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(54) System and method for multi-level phase modulated communication

(57) A method for transmitting a signal includes providing a source signal and splitting the source signal into a first and second split signal. The first split signal is modulated based on a first dataset. The second split signal is phase shifted and modulated based on a second dataset. The modulated second signal is orthogonally polarized with respect to the polarization of the modulated first signal and combined with the modulated first signal. The combined signal may also be modulated and transmitted.

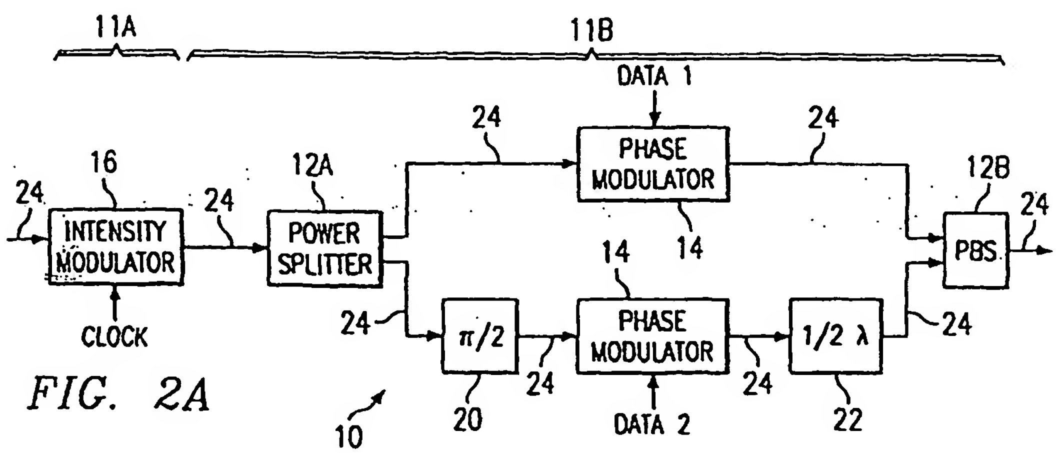

FIG. 2A

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Description

TECHNICAL FIELD OF THE INVENTION

[0001] The present invention relates generally to communication networks and, more particularly, to a system and method for multi-level phase modulated communication.

BACKGROUND OF THE INVENTION

[0002] Telecommunications systems, cable television systems, and data communication networks use optical networks to rapidly convey large amounts of information between remote points. In an optical network, information is conveyed in the form of optical signals through optical fibers. Optical fibers comprise thin strands of glass capable of transmitting the signals over long distances with very little loss. The optical signals have at least one characteristic modulated to encode audio, video, textual, real-time, non-real-time and/or other suitable data. Modulation may be based on phase shift keying (PSK), intensity shift keying (ISK), or other suitable methodologies.

[0003] In Quadrature Phase Shift Keying (QPSK) modulation, the phase of a carrier signal is modulated and takes on one of four possible values corresponding to a symbol set. In QPSK, the carrier signal may be split into two arms, the first of which, called the in-phase component, is phase modulated directly. The second arm, called the quadrature component, may be phase modulated after an additional ninety degree phase shift. The two arms are combined to produce one QPSK signal.

[0004] QPSK receivers use a Phase Locked Loop (PLL) with a local oscillator. Insufficient PLL response time leads to crosstalk between the in-phase and quadrature components of the QPSK signal, resulting in signal quality degradation.

SUMMARY OF THE INVENTION

[0005] In accordance with the present invention, a system and method for multi-level phase modulated communication are provided which substantially eliminate or reduce disadvantages and problems associated with previous systems and methods.

[0006] A method for transmitting a signal includes providing a source signal and splitting the source signal into a first and second split signal. The first split signal is modulated based on a first dataset. The second split signal is phase shifted and modulated based on a second dataset. The polarization of the modulated second signal is rotated or otherwise controlled to be orthogonal with respect to the polarization of the modulated second signal and combined with the modulated first signal. The combined signal may also be modulated and transmitted.

[0007] In another embodiment, a method for receiving a signal includes receiving a signal and providing a local signal. The local signal is circularly polarized and combined with the received signal. The combined signal is split into a first and second split signal and the first and second split signals are detected. Feedback is generated to modify the local signal.

[0008] Embodiments of the invention provide various technical advantages. Technical advantages include providing a method for transmitting a signal, which includes polarization multiplexing of I and Q components in QPSK. The polarization multiplexing reduces crosstalk in the presence of phase errors. Another technical advantage includes taking advantage of polarization multiplexing of I and Q components at the receiver, thereby reducing crosstalk and simplifying the receiver design. An additional technical advantage includes providing a transmitter and receiver configuration for polarization multiplexed and intensity modulated QPSK. Still another technical advantage includes providing intensity modulation to a modified QPSK signal in order to suppress degradation caused by SPM/XPM+GVD in transmission over optical fiber.

[0009] Still another technical advantage includes the use of intensity modulation at the transmitter to improve nonlinear tolerance of QPSK. Moreover, other technical advantages of the present invention will be readily apparent to one skilled in the art from the following figures, descriptions, and claims. Moreover, while specific advantages have been enumerated above, various embodiments may include all, some, or none of the enumerated advantages.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] For a more complete understanding of the present invention and its advantages, reference is now made to the following description, taken in conjunction with the accompanying drawings, in which:

FIGURE 1 is a block diagram illustrating an optical communication system in accordance with one embodiment of the present invention;

FIGURES 2A-B are block diagrams illustrating the optical transmitter of FIGURE 1 in accordance with several embodiments of the present invention;
FIGURE 3 is a block diagram illustrating the optical transmitter of FIGURE 2A, implemented in a planar lightwave circuit, in accordance with one embodiment of the present invention;
FIGURE 4 is a block diagram illustrating the optical transmitter of FIGURE 2A, implemented with discrete elements, in accordance with one embodiment of the present invention;
FIGURE 5 is a block diagram illustrating the optical transmitter of FIGURE 2A, implemented with free space optics, in accordance with one embodiment of the present invention;
FIGURE 6 is a block diagram illustrating the optical receiver of FIGURE 1 in accordance with one embodiment of the present invention;
FIGURE 7 is a block diagram illustrating the optical receiver of FIGURE 6, implemented in a planar lightwave circuit, in accordance with one embodiment of the present invention;
FIGURE 8 is a block diagram illustrating the optical receiver of FIGURE 6, in accordance with one embodiment of the present invention;
FIGURE 9 is a flow diagram illustrating a method for transmitting a signal in accordance with one embodiment of the present invention; and
FIGURE 10 is a flow diagram illustrating a method for receiving a signal in accordance with one embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0011] FIGURE 1 illustrates an optical communications system in accordance with one embodiment of the present invention. Optical communications system 1 includes a transmission module 2 coupled to a receiver module 3 via an optical link 4. Transmission module 2 generates optical signals based on data for transmission over optical link 4 to receiver module 3. Receiver module 3 receives the optical signals and extracts the data.

[0012] Transmission module 2 includes a multiplexer 5 and a plurality of optical transmitters 10. Optical transmitters 10 modulate a signal based on data to produce a modulated signal. In one embodiment, each optical transmitter 10 produces a modulated signal on a distinct wavelength. As used throughout, each means all of a particular subset. Multiplexer 5 receives the modulated signals generated by the optical transmitters 10 and combines them for transmission over optical link 4. In one embodiment, the signals are combined according to a Dense Wavelength Division Multiplexing (DWDM) technique. Once combined, the resultant optical signal is transmitted over optical link 4 to receiver module 3.

[0013] Optical link 4 includes one or more spans of optical fiber. The optical fiber may be constructed of glass, a liquid core in a plastic casing, or otherwise suitably constructed to transmit optical signals. One or more optical amplifiers may also be distributed along the one or more spans of optical fiber.

[0014] Receiver module 3 includes a demultiplexer 6 and a plurality of optical receivers 8. Demultiplexer 6 receives the combined optical signal over optical link 4 and extracts the original modulated signals used to create the combined optical signal. In one embodiment, the combined optical signal is a DWDM signal and is demultiplexed accordingly. Demultiplexer 6 transmits the extracted modulated signals to the optical receivers 8 on a one-to-one basis. The extracted modulated signals may also be distributed in a variety of ways, including, for example, distribution based on traffic volume or on an as available basis. Optical receivers 8 receive the extracted modulated signals and extract the data used by optical transmitters 10 to produce the modulated signals.

[0015] FIGURE 2A illustrates details of the optical transmitter 10 in accordance with one embodiment of the present invention. In this embodiment, optical transmitter 10 is a multi-stage modulator. The first stage 11A modulates a signal for transmission using intensity modulation. The second stage 11B modulates the first stage signal using a combination of Quadrature Phase Shift Keying (QPSK) with polarization multiplexing. Optical transmitter 10 may include other or different suitable stages. For example, optical transmitter 10 may instead modulate a signal using QPSK and then modulate the intensity of the QPSK signal. While the present invention is described in an optical communications system, it will be understood that other suitable systems may also be employed, such as microwave communication systems, for example.

[0016] Referring to FIGURE 2A, a first stage 11A includes intensity modulator 16. Intensity modulator 16 is operable to modulate the intensity of an optical signal based on data. In the illustrated embodiment, intensity modulator 16 modulates the intensity of an optical signal based on a clock signal. The clock signal may be a symbol synchronous sinusoidal clock signal, synchronized with a data signal. It will be understood that other suitable signals or data may be used to provide the data by which intensity modulator 16 modulates the intensity of an optical signal.

[0017] The second stage 11B includes a power splitter 12A, a polarization beam splitter 12B, a plurality of phase modulators 14, a phase shifter 20, a half-wave plate 22, and a plurality of optical links 24. Power splitter 12A is any device operable to receive a plurality of signals and combine or otherwise passively generate a combined signal based

on the received signals and/or to receive a signal and to split the received signal into discrete signals or otherwise passively generate discrete signals based on the received signal. The discrete signals may be identical in form and/ or process or may suitably differ. Polarization beam splitter 12B is any device operable to receive a plurality of signals and combine or otherwise passively generate a combined signal based on the received signals and their associated polarization and/or to receive a signal and to split the received signal into discrete signals or otherwise passively generate discrete signals of disparate polarization states based on the received signal. Phase modulator 14 is operable to modulate the phase of an optical signal based on data.

[0018] Phase shifter 20 is operable to shift a phase of an optical signal. Half wave plate 22 is operable to rotate the polarization of an optical signal by ninety degrees. Optical links 24 link the various components of optical transmitter 10 as shown in FIGURE 2A. In particular, an optical link 24 connects an intensity modulator 16 with a power splitter 12A. Optical links 24 connect power splitter 12A with a first phase modulator 14 and the phase shifter 20. Optical links 24 connect the first phase modulator 14 with a polarization beam splitter 12B. Optical links 24 connect the first phase shifter 20 with a second phase modulator 14 and the second phase modulator 14 with the half wave plate 22. Optical link 24 also connects the half wavelength plate 22 with the polarization beam splitter 12B. Each optical link 24 may be an optical fiber and may be formed with varying types of materials that affect the transport characteristics of light flows along optical link 24.

[0019] In operation, optical transmitter 10 receives a carrier signal, modulates the carrier signal intensity, splits the intensity modulated signal into two arms and modulates the phase of each arm to produce a combined quadrature phase shift keying (QPSK) signal resulting in intensity modulated quadrature phase shift keying (IM/QPSK). In QPSK modulation, the phase of the carrier signal is modulated and takes on values from the set [-45°, 45°, 135°, -135°] corresponding to the symbol set [10, 11, 01, 00], respectively.

[0020] The carrier signal may be provided by a continuous wave laser and may be mathematically expressed, for example, as A $\cos(2\pi f_c t)$, where A is amplitude, f_c is the carrier frequency, and t is time.

[0021] The carrier signal is first intensity modulated by intensity modulator 16. In the illustrated embodiment, the carrier signal is modulated based on a twenty GHz symbol synchronous clock signal, synchronized with a data signal. Intensity modulator 16 transmits the intensity modulated signal to the power splitter 12A.

[0022] The intensity modulated signal enters the power splitter 12A where it is split into two signals, the first of which travels along an optical link 24 to the first phase modulator 14. Phase modulator 14 directly phase-modulates the signal based on a first data source at twenty Gb/s, the resulting signal called the in-phase component (I component). The in-phase component travels along optical link 24 to the polarization beam splitter 12B, in this case functioning as a combiner.

[0023] The second signal coming from power splitter 12A travels along optical link 24 to phase shifter 20. Phase shifter 20 shifts the phase of the carrier source signal by 90 degrees. In some embodiments, phase shifter 20 may be "invisible" — for example, a direct current (DC) voltage may be applied to the second phase modulator 14 to effect the phase shift. Alternatively, the phase may be shifted by manipulating the optical path length or by taking advantage of the electro-optic effect and/or nonlinearity, or other suitable methods.

[0024] After the carrier signal is phase shifted, the phase-shifted signal travels along optical link 24 to the second phase modulator 14, where the phase-shifted signal is directly phase-modulated by a second data source at 20 Gb/s, resulting in a signal called the quadrature component (Q component). The quadrature component travels along optical link 24 to half wave plate 22, where the signal polarization is rotated by ninety degrees, such that it is orthogonal to the polarization of the in-phase component generated by first phase modulator 14.

[0025] In a particular embodiment, where the carrier signal is launched in transverse electric (TE) polarization, half wave plate 22 converts it to transverse magnetic (TM) polarization. TE and TM polarization may be described by the following mathematical formulae:

TE = E_x cos (™$_c$t) ℘ + E_y cos (™$_c$t + 2) ↓, where E_y = 0

TM = E_x cos (™$_c$t) ℘ + E_y cos (™$_c$t + 2) ↓, where E_x = 0

where E_x is the amplitude of polarization in the x-direction, E_y is the amplitude of the polarization in the y-direction, ™$_c$ is the carrier frequency; t is time; ℘ is the unit vector in the direction of the x-axis; ↓ is the unit vector in the direction of the y-axis; and 2 is the arbitrary phase difference. The resultant signals, that is, the I and Q components, are therefore orthogonal to each other, with the I component at transverse electric (TE) polarization and the Q component at transverse magnetic (TM) polarization.

[0026] The in-phase and quadrature components are combined at polarization beam splitter 12B. The combined signal may be described mathematically, for example, as E_x cos (™$_c$t + 2_1(t)) ℘ + E_y sin (™$_c$t + 2_2(t)) ↓, where 2_1(t)

is a first data stream in phase modulated format and $2_2(t)$ is a second data stream in phase modulated format.

[0027] In the illustrated embodiment, the resultant intensity modulated QPSK signal is then sent for transmission along optical link 24. In an exemplary embodiment, the resultant transmission rate is 40 Gb/s symbol synchronous intensity modulated QPSK. As described above, the first stage is intensity modulation with a 20 GHz symbol synchronous sinusoidal clock signal. The second stage is QPSK modulation with polarization multiplexing. Thus, the intensity is reduced when there is a phase discontinuity in the signal. The advantage of intensity modulation is to suppress the degradation caused by SPM/XPM+GVD in transmission over fiber. As will be shown below, in connection with FIGURES 6, 7, and 8, the advantage of polarization multiplexing is to reduce the crosstalk between the in-phase and quadrature components.

[0028] FIGURE 2B illustrates an optical transmitter 10 in accordance with another embodiment of the present invention. Like the optical transmitter of FIGURE 2A, optical transmitter 10 includes a first stage 11A and second stage 11B. First stage 11A modulates an optical signal for transmission using intensity modulation. Second stage 11B modulates the first stage signal using a combination of QPSK with polarization multiplexing.

[0029] First stage 11A includes an intensity modulator 16 operable to modulate the intensity of an optical signal based on a clock signal. Second stage 11B includes a first and second polarization beam splitter 12B, a first and second phase modulator 14, phase shifter 20, and a plurality of optical links 24.

[0030] In operation, optical transmitter 10 functions in a manner substantially similar to the optical transmitter of FIGURE 2A. However, the use of a first polarization beam splitter 12B renders a half wave plate unnecessary. This configuration requires the polarization of the optical signal entering first polarization beam splitter 12B to be linearly polarized at an angle of forty-five degrees relative to an axis of the first polarization beam splitter 12B.

[0031] FIGURE 3 illustrates an implementation of the system of FIGURE 2A, in particular, a planar light wave circuit. Planar light wave circuit 30 includes a power splitter 12A, a polarization beam splitter 12B, a plurality of phase modulators 14, a half wavelength plate 22, and a plurality of optical links 24 interconnecting the components.

[0032] In operation, the carrier signal enters an ingress section of planar light wave circuit 30, where the signal is split into two branches by the power splitter 12A. The first branch proceeds to a first phase modulator 14 wherein the carrier signal is directly phase modulated according to a first dataset received along the electrical wave guide (hatched) to generate a first modulated signal (the I component). The second branch of the split signal travels to the second phase modulator 14, which shifts the phase of the carrier signal and modulates the phase shifted signal based on a second dataset received along the electrical wave guide (hatched) to generate a second modulated signal (the Q component). After modulation based on the second dataset, the modulated signal travels along optical link 24 to half wavelength plate 22, where the polarization of the Q component is rotated to be orthogonal to the polarization of the I component. The in-phase and quadrature components travel along optical links 24 to the polarization beam splitter 12B, where the signals are combined and travel out of planar light wave circuit 30 through an egress section. From planar light wave circuit 30, the resultant QPSK signal may then be intensity modulated in a similar fashion to that shown in accordance with FIGURE 2A (not shown here). Alternatively, the carrier signal may be intensity modulated before it enters planar light wave circuit 30. Planar light wave circuit 30 may be constructed of various materials conducive to transmission of optical signals or light through the material, such as, for example, lithium niobate or silica.

[0033] FIGURE 4 illustrates an embodiment of the system of FIGURE 2A as discrete elements connected by optical fiber. Optical transmitter 40 includes polarization maintaining fiber (PMF) 42 connecting a splitter 12A with a pair of phase modulators 14 and a phase shifter 20. PMF 42 further connects the phase modulators 14 to polarization beam splitter 12B. In operation, a carrier signal enters the splitter 12A, where it is split into two arms, each of which travel along PMF 42 to the first and second phase modulators. In the second arm, the signal passes through the phase shifter 20 before the phase modulator. The first phase modulator 14 modulates a phase of the signal based on a first dataset, to generate a first modulated signal (the I component). Phase shifter 20 shifts the phase of the optical signal on the second arm. Second phase modulator 14 modulates the phase of the second arm of the carrier signal based on a second dataset, to generate a second modulated signal (the Q component). The polarization of the Q component is rotated to be orthogonal to the polarization of the I component. The quadrature (Q) component proceeds along PMF 42 to the polarization beam splitter 12B. The in-phase and quadrature components are combined at polarization beam splitter 12B where the combined signal may be then passed to an intensity modulator for intensity modulation and further transmission.

[0034] FIGURE 5 illustrates the system of FIGURE 2A, in a free space optics environment in accordance with yet another embodiment of the present invention. Optical transmitter 50 includes optical links 24, two phase modulators 14, polarization beam splitter 12, half wave plate 22, half mirror 52, mirrors 54, and lenses 56. In operation, the carrier signal passes through optical link 24 and shines onto lens 56, which concentrates the light onto half mirror 52. Half mirror 52 is operable to split the light into two discrete beams, each of which passes to one of the phase modulators 14. The first phase modulator 14 modulates the phase of the light beam based on a first dataset and the second phase modulator 14 shifts the phase of the signal and modulates the phase-shifted beam of light based on a second dataset. Both beams leave their respect phase modulators 14 and travel to a mirror 54. The light beam of phase modulated

light from the first phase modulator 14 reflects from the first mirror 54 directly to the polarization beam splitter 12 (the in-phase (I) component). The second phase modulated light reflects from the second mirror 54 and passes through half wave plate 22, where the light is polarized to be orthogonal to the I component. The resultant light beam (the Q component) passes from half wave plate 22 to polarization beam splitter 12, where it is combined with the I component. The combined light beam shines on a second lens 56, where it is concentrated on an input side of optical link 24 for further transmission. A power combiner may be used in place of the polarization beam splitter 12. In addition, in another embodiment, a polarization beam splitter 12 may be used in place of half mirror 52 and the half wave plate 22 omitted. In this embodiment, the signal is linearly polarized at 45 degrees relative to the axis of the polarization beam splitter.

[0035] FIGURE 6 illustrates details of an the optical receiver 8 of FIGURE 1, in accordance with one embodiment of the present invention. In this embodiment, optical receiver 8 receives and processes different types of signals. Optical receiver 8 includes a plurality of optical links 24, a first splitter 62, a polarization beam splitter 64, a plurality of photodiodes 66, and electrical links 67. Optical receiver 8 also includes a decision circuit 68, a feedback control 70, a local oscillator 72, and a quarter wave plate 74. First splitter 62 is operable to receive an optical signal at an ingress section from optical link 24 and to combine that signal with a local oscillator signal received from the optical link 24 connecting first splitter 62 to quarter wave plate 74. First splitter 62 is operable to combine these two signals and transmit them along optical link 24 to polarization beam splitter 64. It will be understood that the first splitter 62 may be any optical coupler operable to combine the received signal from the in branch of optical link 24 and the signal received from quarter wave plate 74. Thus, splitter 62 may be a half mirror, a 50-50 path splitter/combiner, a fusion fiber coupler, a three decibel coupler, or any other device operable to combine the two signals and produce a single output in the most efficient way.

[0036] Polarization beam splitter 64 is operable to split the signal received from first splitter 62 into discreet signals or otherwise passively generate discreet signals based on the received signal. Polarization beam splitter 64 is operable to split the signal received from first splitter 62 into its transverse electric (TE) and transverse magnetic (TM) components. Thus, in this embodiment, any phase error in the local oscillator 72 will only result in signal attenuation, not cross-talk. Thus, the polarization beam splitter 64 is operable to split the received signal into its I and Q components by differentiating between the different polarizations associated with each component. That is, transverse electric (TE) for the in-phase component and transverse magnetic (TM) for the quadrature component. Each component is received by a photodiode 66 which, as mentioned below, converts the signals into an electrical signal which is then processed by decision circuit 68. The split signals from polarization beam splitter 64 travel along optical links 24 to photodiodes 66.

[0037] Photodiodes 66 are operable to convert the optical signals received from the polarization beam splitter 64 into electrical signals, which are then transmitted along electrical links 67 to decision circuit 68. Decision circuit 68 then retrieves the various components of the optical signals and converts them into the intended data streams.

[0038] Decision circuit 68 is connected to a feedback control 70 along an electrical link 67. Feedback control 70 is operable to modify the output of local oscillator 72 through a control link via electrical link 67, based on information received from decision circuit 68. Feedback control 70 operates in a fashion similar to a phase lock loop (PLL), and is used to minimize phase noise. Local oscillator 72 is operable to provide an optical output, in a similar fashion to the carrier source of FIGURE 2. The local oscillator signal travels along optical link 24 to quarter wave plate 74. Quarter wave plate 74 is operable to transform a linearly polarized signal received from local oscillator 72 into circular polarization and to transmit that circularly polarized signal along optical link 24 for combination with the input signal at first splitter 62.

[0039] In this embodiment it is assumed that the received light at first splitter 62 has already been aligned with the I component of the signal, that is, the received signal is in transverse electric (TE) polarization. This may be performed by, for example, an automatic polarization controller (APC) device, or other suitable devices. The signal received by first splitter 62 may also be filtered with a polarization mode dispersion compensator (PMDC) device along with the automatic polarization controller (APC). It will also be understood by those skilled in the art that where the local oscillator 72 emits circularly polarized light, there is no need for the quarter wave plate 74.

[0040] FIGURE 7 illustrates the optical receiver of FIGURE 6, as implemented in a planar light wave circuit, in accordance with one embodiment of the present invention. Optical receiver 80 includes planar light wave medium 82, a plurality of optical links 24, a first splitter 62, a polarization beam splitter 64, two or more photodiodes 66, a quarter wave plate 74, and a local oscillator 72. Planar light wave medium 82 may comprise any suitable medium operable to propagate light. Planar light wave medium 82 may comprise, for example, lithium niobate, silica and the like.

[0041] In operation, an optical signal is received at the in side of optical receiver 80 and travels along optical link 24 where it is combined with a signal received from local oscillator 72 at first splitter 62. Local oscillator 72, as described above, in conjunction with FIGURE 6, produces a signal that travels along an optical link 24 to a quarter wave plate 74, where the signal is circularly polarized. The circularly polarized signal is combined with the received signal at first splitter 62. The combined signal passes along an optical link 24 to the polarization beam splitter 64 where the signal is split into the I and Q components. The I and Q optical signals are then transmitted to a photodiode 66 where they are converted into electrical signals for processing.

[0042] FIGURE 8 illustrates the optical receiver of FIGURE 6, as implemented in a free space optics environment, in accordance with one embodiment of the present invention. Optical receiver 90 includes an optical link 24, lenses 92, a plurality of light beams 94, a half mirror 96, a polarization beam splitter 64, a mirror 98, two or more photodiodes 66, a local oscillator 72, and a quarter wave plate 74. In operation, an optical signal is received at the in node at optical link 24, where the optical signal is received on a lens 92, which converts the optical signal into a light beam 94. Light beam 94 travels to half mirror 96 where it is combined with a signal received and reflected off of mirror 98. Local oscillator 72 generates a carrier signal along another optical link 24, which travels to a second lens 92 converting the signal into a light beam 94. The light beam then passes through a quarter wave plate 74, which, as described above, ensures that the light is circularly polarized. The circularly polarized light reflects off of mirror 98 to half mirror 96, where it is combined with the light beam generated by lens 92. The combined light passes to a polarization beam splitter 64 where the light is split into I and Q components and shines onto two or more photodiodes 66. As described above, photodiodes 66 are operable to convert the received light of the I and Q components of the signal from an optical to an electrical signal for further processing. Mirror 98 can be eliminated by locating local oscillator 72, lens 92, light beam 94, and quarter wave plate 74 in a vertical configuration. Further details of the present invention will become apparent in connection with the methods described in FIGURES 9 and 10.

[0043] FIGURE 9 is a flow diagram illustrating a method for transmitting a signal in accordance with one embodiment of the present invention. In this embodiment, intensity modulation independent of polarization state of the signal is performed at the second stage, with phase modulation being performed at the first stage.

[0044] The process begins at step 100 wherein a carrier signal is provided. As described above, this step may be performed by a local oscillator or continuous wave laser, or other means suitable to produce a carrier signal. Next, at step 105, the carrier signal is split into two discreet arms. As described above, this step may be, for example, performed by the beam splitter 12A of FIGURE 2A, or, for circularly polarized light by a polarization beam splitter.

[0045] At step 110, the first split signal is modulated based on a first data input. This step may be performed by the first phase modulator 14 of FIGURE 2A. Next, at step 115, the phase of the second split signal split in step 105 above is shifted by $\pi/2$ radians. As described above, this may be performed by the phase shifter 20 of FIGURE 2A. Next, at step 120, the phase shifted second split signal is modulated based on a second data input. This step may be performed by the second phase modulator 14 of FIGURE 2A.

[0046] Next, at step 125, the polarization of the second modulated signal is made orthogonal to polarization of the first modulated signal. This step may be performed by the half wave plate 22 of FIGURE 2A, or otherwise suitably polarized. Next, at step 130, the modulated first signal and the orthogonally polarized second signal are combined. This step may be performed by the polarization beam splitter 12B of FIGURE 2A or a splitter. At step 135, the combined signal is modulated. This step may be performed by intensity modulator 16 in an embodiment in which it is the second stage and may be modulated based on a clock signal. Next, at step 140, the modulated combined signal is transmitted and the process ends.

[0047] FIGURE 10 is a flow diagram illustrating a method for receiving and processing a signal in accordance with another embodiment of the present invention. The process begins at step 200 wherein an intensity modulated QPSK signal is received. At step 205 a local signal is provided. This step may be performed by, for example, local oscillator 72 of FIGURE 6. At step 210 the local signal is transformed to a circular polarization. As described above, this step may be performed by the quarter wave plate 74 of FIGURE 6.

[0048] At step 215, the polarized local signal is combined with the received signal. This step may be performed by the first splitter 62 of FIGURE 6. At step 220, the combined signal is then split into two discreet signals. This step may be performed by the polarization beam splitter 64 of FIGURE 6.

[0049] At step 225, a first component of the split signal is detected. This may be either the I or Q components of the received signal, and may be performed by photodiode 66 of FIGURES 6, 7, and 8. At step 230, a second component of the split signal is detected, the other of the two signals. That is, if the I component is detected at step 225, then the Q component is detected at step 230. As with step 225, this step may be performed by photodiode 66 of FIGURES 6, 7, and 8.

[0050] At step 235, feedback is generated to modify the local signal in order to provide a phase locked look (PLL) for the receiver. This step may be performed by decision circuit 68 and feedback control 70 of FIGURE 6. At step 240, the process repeats, wherein a signal is received (Step 200).

[0051] Although the methods of FIGURES 9 and 10 have been shown with specific steps in a specific order, it will be understood that the steps may be performed in a different order as appropriate, and other steps may be added or omitted as appropriate in keeping with the spirit of the present invention.

[0052] Although the present invention has been described with several embodiments, various changes and modifications may be suggested to one skilled in the art. It is intended that the present invention encompass its changes and modifications as fall within the scope of the appended claims.

Claims

1. A method for modulating a signal for transmission, comprising:

   receiving a source signal;
   splitting the source signal into a first split signal and second split signal;
   modulating the first split signal based on a first dataset to generate a first modulated signal;
   shifting a phase of the second split signal to generate a phase-shifted second split signal;
   modulating the phase-shifted second split signal based on a second dataset to generate a modulated second signal;
   controlling the polarization of the modulated second signal; and
   combining the modulated first signal and the modulated second signal to generate a combined signal.

2. The method of Claim 1, wherein the polarization of the second signal is controlled to be orthogonal to the polarization of the modulated first signal.

3. The method of Claim 1, wherein the phase-shift is ninety degrees.

4. The method of Claim 1, wherein immediately prior to combination, the polarization of the modulated first signal is transverse electric (TE) polarization, and the polarization of the polarized second signal is transverse magnetic (TM) polarization.

5. The method of Claim 1, wherein the modulation is by phase modulation.

6. The method of Claim 1, further comprising modulating the source signal.

7. The method of Claim 6, wherein the source signal is modulated by intensity modulation.

8. The method of Claim 7, wherein the intensity modulation is periodic.

9. The method of Claim 7, wherein the intensity modulation is by a clock signal whose frequency and phase are synchronized with a data signal.

10. The method of Claim 1, wherein the signal is optical.

11. The method of Claim 1, further comprising modulating the combined signal.

12. A method for receiving a signal, comprising:

    generating a polarized signal based on receiver-side feedback;
    combining an ingress traffic signal with the polarized signal to generate a combined signal;
    splitting the combined signal into a first split signal and second split signal;
    detecting the first split signal; and
    detecting the second split signal.

13. The method of Claim 12, wherein the ingress traffic signal is compensated for polarization mode dispersion.

14. The method of Claim 12, wherein the polarization is circular.

15. The method of Claim 12, wherein the first split signal comprises a first component of the received signal.

16. The method of Claim 12, wherein the second split signal comprises a second component of the received signal.

17. The method of Claim 12, wherein the ingress traffic signal is optical.

18. The method of Claim 12, wherein the combined signal is split by a polarization beam splitter (PBS).

19. The method of Claim 18, wherein the polarization of a first component of the ingress traffic signal is aligned to an

axis of the polarization beam splitter.

20. A system for transmitting a signal, comprising:

a means for providing a source signal;
a means for splitting the source signal into a first split signal and second split signal;
a means for modulating the first split signal based on a first dataset to generate a modulated first split signal;
a means for shifting a phase of the second split signal to generate a phase-shifted second split signal;
a means for modulating the phase-shifted second split signal based on a second dataset to generate a modulated second signal;
a means for controlling the polarization of the modulated second signal to generate a polarized signal; and
a means for combining the modulated first split signal and the polarized signal to generate a combined signal.

21. The system of Claim 20, wherein the polarization of the modulated second signal is orthogonal to the polarization of the modulated first signal.

22. The system of Claim 20, wherein the phase shift is ninety degrees;

23. The system of Claim 20, wherein immediately prior to combination, the polarization of the modulated first signal is transverse electric (TE) polarization, and the polarization of the polarized second signal is transverse magnetic (TM) polarization.

24. The system of Claim 20, wherein the modulation is by phase modulation.

25. The system of Claim 20, further comprising a means for modulating the source signal.

26. The system of Claim 25, wherein the source signal is modulated by intensity modulation.

27. The system of Claim 26, wherein the intensity modulation is periodic.

28. The system of Claim 26, wherein the intensity modulation is by a clock signal whose frequency and phase are synchronized with a data signal.

29. The system of Claim 28, wherein the clock signal is at a symbol rate.

30. The system of Claim 20, wherein the signal is optical.

31. The system of Claim 20, wherein the source signal means is a continuous wave laser.

32. The system of Claim 20, wherein the source signal is split by a polarization beam splitter; and
wherein the source signal is circularly polarized.

33. The system of Claim 20, wherein the source signal is split by a half mirror.

34. The system of Claim 20, wherein the source signal is split by a three decibel splitter.

35. The system of Claim 20, wherein the phase shift means is by applying direct current (DC) voltage to the modulator.

36. The system of Claim 20, wherein the means for controlling polarization is a half-wave plate.

37. A system for receiving a signal comprising:

a means for receiving a signal;
a means for providing a local signal;
a means for controlling a polarization of the local signal to generate an appropriately polarized local signal;
a means for combining the polarized local signal and received signal;
a means for splitting the combined signal into a first split signal and a second split signal;
a means for detecting the first split signal;

a means for detecting the second split signal; and
a means for generating feedback to modify the local signal.

38. The system of Claim 37, wherein the received signal is compensated for polarization mode dispersion.

39. The system of Claim 37, wherein the signal is received by an automatic polarization controller.

40. The system of Claim 37, wherein the appropriate polarization of the local signal is circular.

41. The system of Claim 37, wherein the first split signal comprises a first component of the received signal.

42. The system of Claim 37, wherein the second split signal comprises an orthogonally polarized second component of the received signal.

43. The system of Claim 37, wherein the signal is optical.

44. The system of Claim 37, wherein the local signal is provided by a continuous wave laser.

45. The system of Claim 37, wherein the local signal means yields circularly polarized light.

46. The system of Claim 37, wherein the means to control polarization is a quarter wave plate.

47. The system of Claim 37, wherein the combiner means is a 3 decibel splitter.

48. The system of Claim 37, wherein the combiner means is a half mirror.

49. The method of Claim 37, wherein the splitting means is a polarization beam splitter; and
a first component of the signal is aligned to an axis of the polarization beam splitter.

50. The system of Claim 37, wherein the detecting means is a photodiode.

51. An optical transmitter, comprising:

a carrier signal generator, operable to generate an optical signal;
an intensity modulator, optically coupled to the carrier signal generator and operable to modulate an intensity of the optical signal to generate an intensity modulated signal;
a first beam splitter, optically coupled to the intensity modulator and operable to receive and divide the intensity modulated signal into two separate signals;
a first phase modulator, optically coupled to the first beam splitter and operable to receive a data stream and modulate a phase of an optical signal based on the data stream to generate a first modulated signal;
a phase shifter, optically coupled to the first beam splitter and operable to shift a phase of an optical signal;
a second phase modulator, optically coupled to the phase shifter and operable to receive a data stream and modulate a phase of an optical signal based on the data stream to generate a second modulated signal;
a half wave plate, optically coupled to the second phase modulator and operable to receive the second modulated signal and generate a signal with a polarization state that is orthogonal to the polarization state of the first modulated signal to generate an orthogonal signal;
a second polarization beam splitter, optically coupled to the first phase modulator and the half wave plate and operable to combine the first modulated signal with the orthogonal signal to generate a combined signal.

52. An optical receiver, comprising:

a local oscillator optically coupled to a quarter wave plate and operable to generate an optical signal;
the quarter wave plate optically coupled to a first beam splitter and operable to receive an optical signal, circularly polarize the optical signal to generate a circularly polarized signal, and transmit the polarized signal to the first beam splitter;
the first beam splitter optically coupled to a second polarization beam splitter and operable to receive an optical traffic signal, combine the optical traffic signal with the circularly polarized signal to generate a combined signal, and transmit the combined signal to the second polarization beam splitter;

the second polarization beam splitter optically coupled to a first photodiode and a second photodiode and operable to receive the combined signal, split the combined signal into a first split signal and a second split signal, and transmit the first split signal to the first photodiode and the second split signal to the second photodiode;
the first photodiode coupled to a decision circuit and operable to receive the first split signal, generate a first data signal based on the first split signal, and transmit the first data signal to the decision circuit;
the second photodiode coupled to a decision circuit and operable to receive the second split signal, generate a second data signal based on the second split signal, and transmit the second data signal to the decision circuit;
the decision circuit coupled to a feedback control module and operable to determine a desired optical signal generated by the local oscillator generate a control signal based on the desired optical signal, and transmit the control signal to the feedback control module;
the feedback control module coupled to the local oscillator and operable to generate an oscillator control signal based on the control signal; and
the local oscillator operable to receive the oscillator control signal and modify the optical signal based on the oscillator control signal.

53. A method for generating a signal for transmission, comprising:

combining a first signal having a first polarization state with a second signal having a second polarization state orthogonal to the first polarization state to generate a QPSK signal; and
intensity modulating a signal associated with the QPSK signal, the signal comprising one of a carrier signal and the QPSK signal.

54. A method for processing a signal, comprising:

receiving an intensity modulated QPSK signal comprising orthogonal components; and
decoding the QPSK signal.

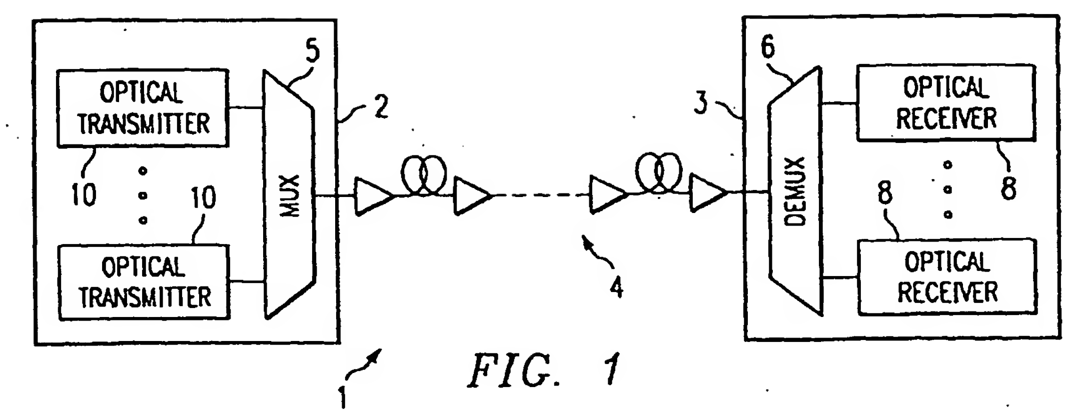


FIG. 1

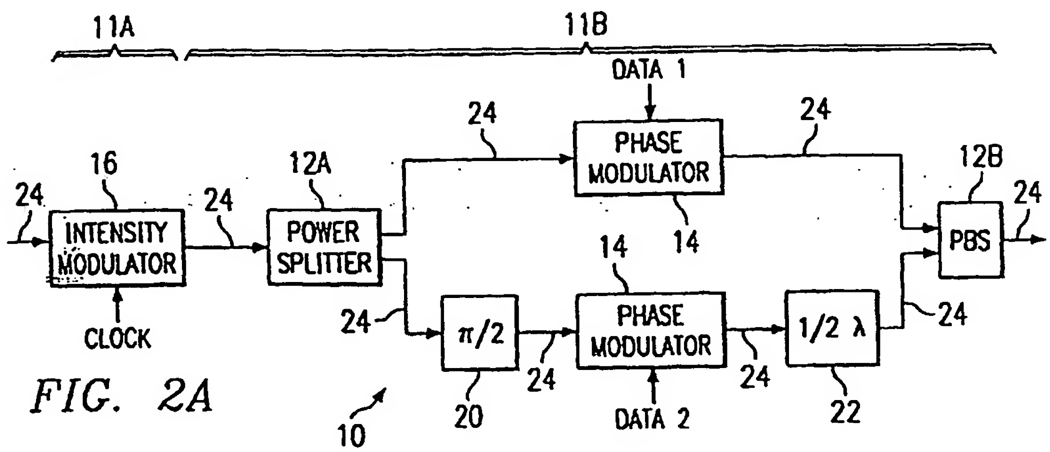


FIG. 2A

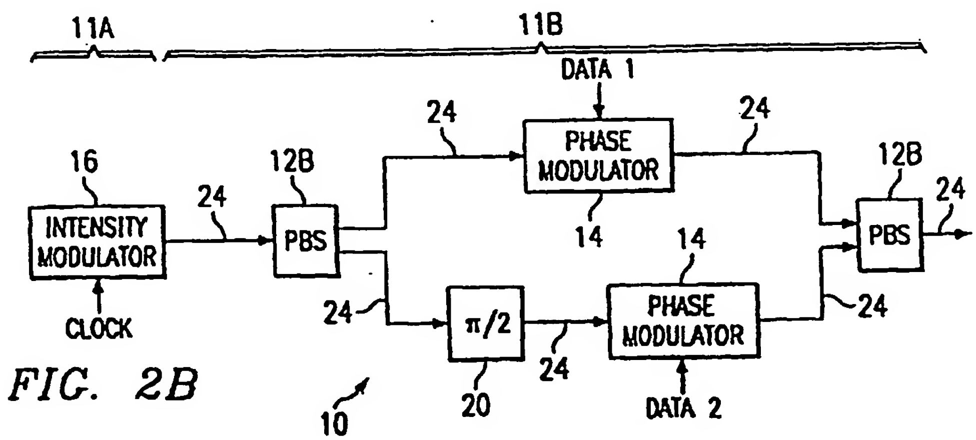


FIG. 2B

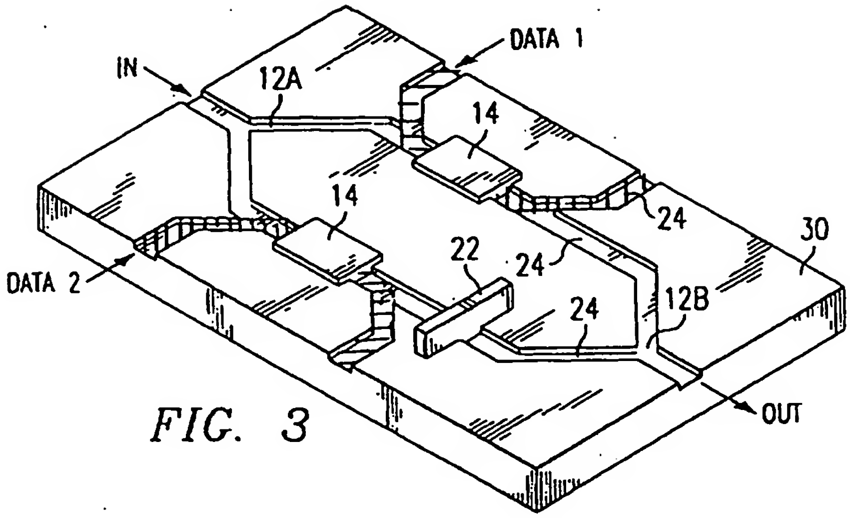


FIG. 3

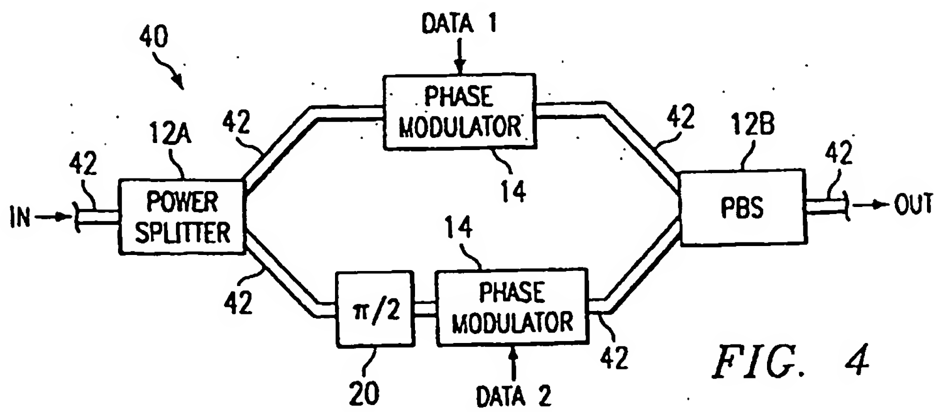


FIG. 4

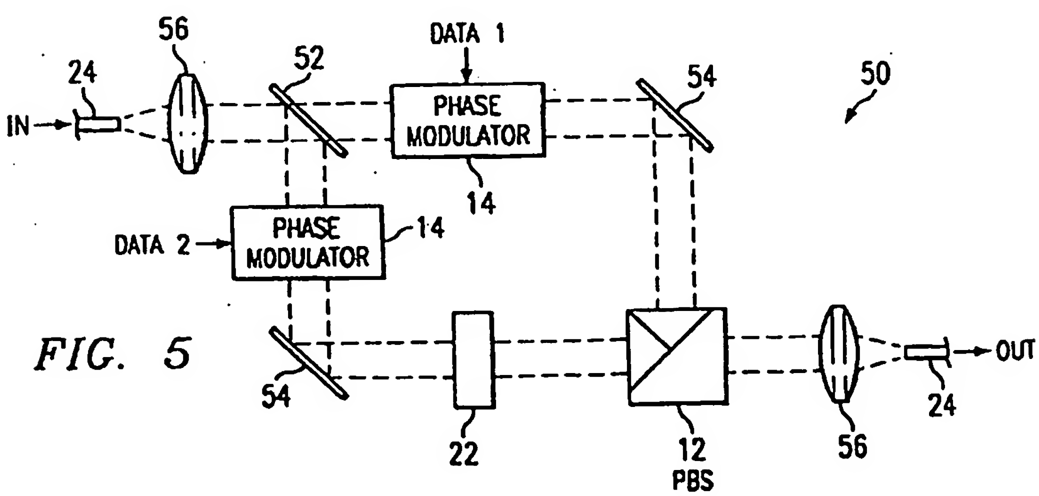


FIG. 5

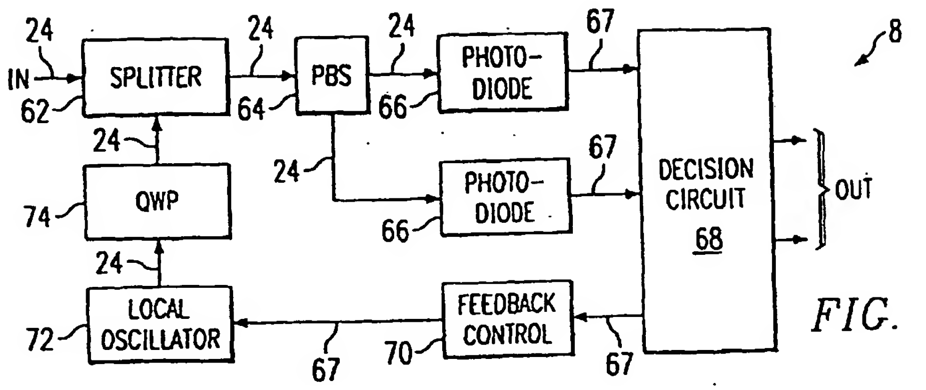


FIG. 6

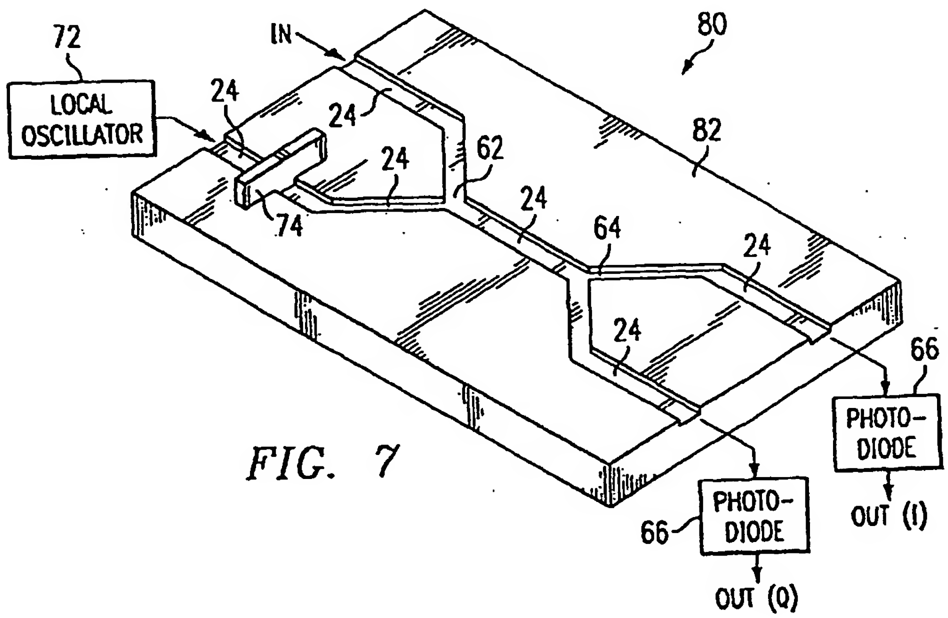


FIG. 7

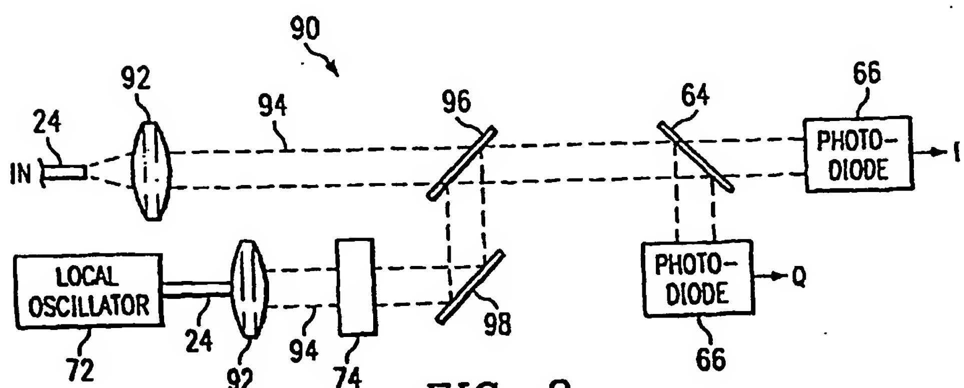


FIG. 8

FIG. 9

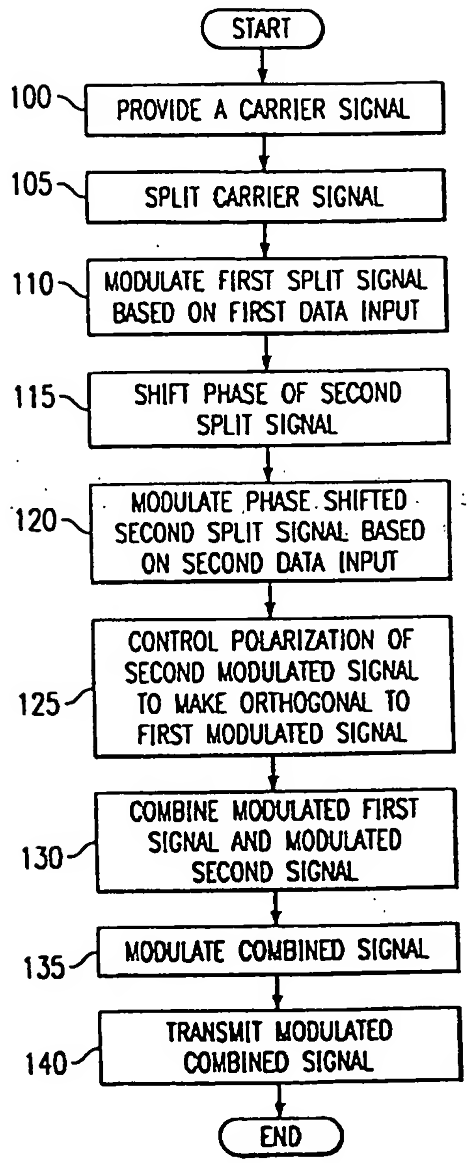
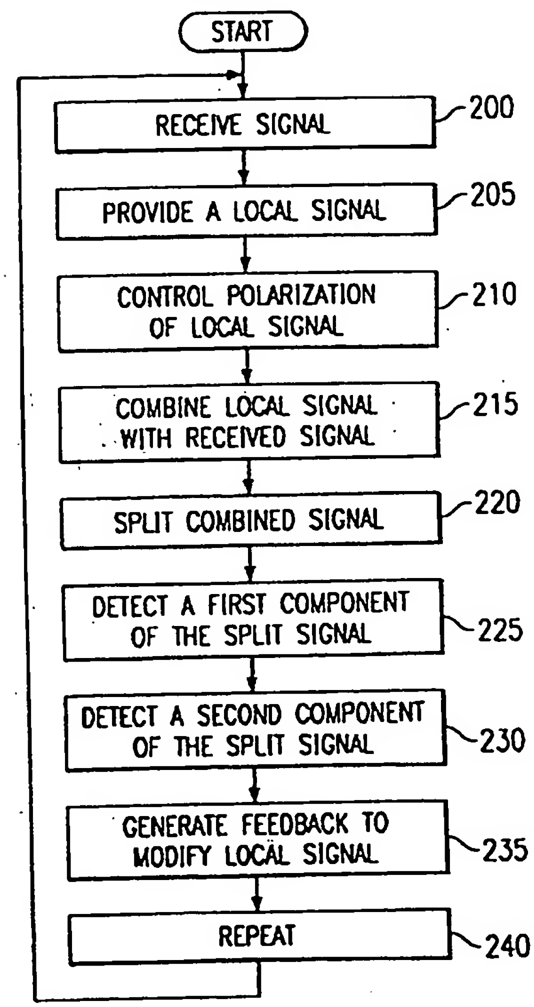

START
100 PROVIDE A CARRIER SIGNAL
105 SPLIT CARRIER SIGNAL
110 MODULATE FIRST SPLIT SIGNAL BASED ON FIRST DATA INPUT
115 SHIFT PHASE OF SECOND SPLIT SIGNAL
120 MODULATE PHASE SHIFTED SECOND SPLIT SIGNAL BASED ON SECOND DATA INPUT
125 CONTROL POLARIZATION OF SECOND MODULATED SIGNAL TO MAKE ORTHOGONAL TO FIRST MODULATED SIGNAL
130 COMBINE MODULATED FIRST SIGNAL AND MODULATED SECOND SIGNAL
135 MODULATE COMBINED SIGNAL
140 TRANSMIT MODULATED COMBINED SIGNAL
END

FIG. 10


START
RECEIVE SIGNAL 200
PROVIDE A LOCAL SIGNAL 205
CONTROL POLARIZATION OF LOCAL SIGNAL 210
COMBINE LOCAL SIGNAL WITH RECEIVED SIGNAL 215
SPLIT COMBINED SIGNAL 220
DETECT A FIRST COMPONENT OF THE SPLIT SIGNAL 225
DETECT A SECOND COMPONENT OF THE SPLIT SIGNAL 230
GENERATE FEEDBACK TO MODIFY LOCAL SIGNAL 235
REPEAT 240

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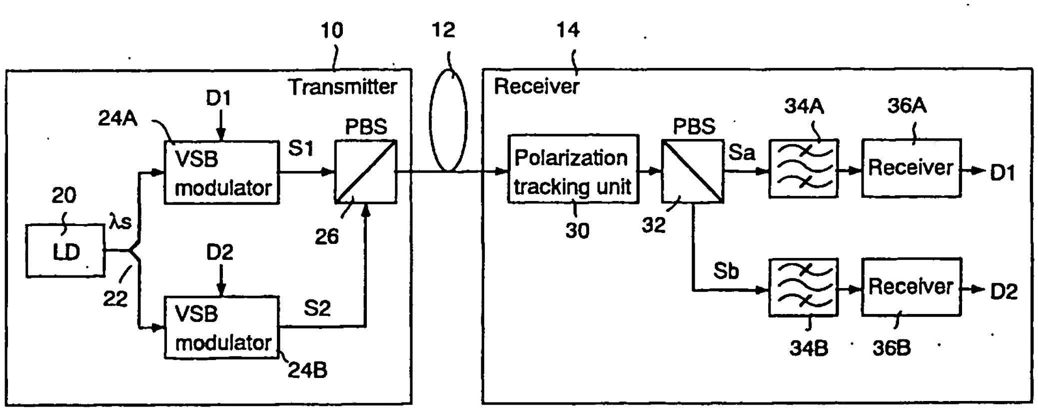
(54) Optical transmission system, optical transmitter and methods thereof

(57) To extend a distance of polarization-multiplexing, an optical transmitter in an optical transmission system has a first signal light output unit (24A, 124A) to output a first signal light (S1) of linear polarization to carry a first data (D1) using VSB modulation having one of sideband on a short wavelength side and sideband on a long wavelength side, a second signal light output unit (24B, 124B) to output a second signal light (S2) of linear polarization to carry a second data (D2) using VSB modulation having the other of sideband on a long wavelength side and sideband on a long wavelength side, and an optical coupler (26, 126) to couple the first signal light (S1) and the second signal light (S2) under different polarizations and output the coupled signal lights onto the optical transmission line (12, 112).

Fig. 1



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Description

FIELD OF THE INVENTION

[0001] This invention relates to an optical transmission system, an optical transmitter, and methods thereof, and more specifically relates to an optical transmission system, an optical transmitter, and method thereof using optical polarization division multiplexing.

BACKGROUND OF THE INVENTION

[0002] In optical fiber transmission, an optical polarization division multiplexing system and a vestigial sideband (VSB) or single sideband (SSB) transmission system is well known as a method to increase a transmission rate of each wavelength. The optical polarization division multiplexing system is a system to transmit a signal using polarizations orthogonal to each other and theoretically it is possible to double a transmission rate. In this specification, both VSB transmission system and SSB transmission system are called generically as a VSB transmission system unless they are purposely distinguished.

[0003] Furthermore, the VSB transmission system transmits an optical carrier component and one sideband component alone after being modulated. By practically narrowing an optical spectral line width, it is possible to perform dense wavelength division multiplexing and accordingly a transmission capacity is expanded.

[0004] Although a number of transmission experiments of optical polarization division multiplexing system have been reported, the transmission distance is several hundred km at very most and there is no report of several thousand km needed for the transoceanic transmission. It is because the orthogonality of polarization necessary for optical polarization division multiplexing transmission becomes out of shape as the transmission distance becomes longer owing to polarization mode dispersion (PMD) and polarization dependent loss (PDL) of an optical fiber transmission line. When the orthogonality of polarization becomes out of shape, crosstalk between polarizations occurs and consequently deteriorates transmission characteristics.

SUMMARY OF THE INVENTION

[0005] An object of the present invention is to provide an optical transmission system using optical polarization division multiplexing, an optical transmitter, and methods thereof applicable to long haul transmission such as a transoceanic transmission.

[0006] An optical transmission system according to the present invention comprises an optical transmitter, an optical transmission line, and an optical receiver. The optical transmitter comprises a first signal light output unit to output a first signal light of linear polarization to carry a first data using VSB modulation having one of sideband on a short wavelength side and sideband on a long wavelength side, a second signal light output unit to output a second signal light of linear polarization to carry a second data using VSB modulation having the other of sideband on a short wavelength side and sideband on a long wavelength side, and an optical coupler to couple the first signal light and the second signal light under different polarizations and output the coupled signal lights onto the optical transmission line. The optical receiver comprises an optical separator to separate a first optical component mainly including the first signal light and a second optical component mainly including the second optical signal out of the light from the optical transmission line, a first receiver to restore the first data from the first optical component, and a second receiver to restore the second data from the second optical component.

[0007] The crosstalk is greatly reduced because the sidebands left for the VSB modulation are transmitted under different polarizations.

[0008] In the optical transmission system according to the present invention, preferably the optical separator comprises a polarization beam splitter and a polarization tracking unit to control a polarization direction of the light from the optical transmission line so that one of polarization directions of the first and second signal lights included in the light from the optical transmission line coincides with that of the polarization beam splitter.

[0009] In the optical transmission system according to the present invention, preferably the optical separator comprises an optical splitter to split the light from the optical transmission line into two portions, a first signal light extractor to extract the first signal light out of one portion of the lights from the optical splitter, and a second signal light extractor to extract the second signal light out of the other portion of the lights from the optical splitter.

[0010] In the optical transmission system according to the present invention, preferably the first signal light extractor comprises a first polarization beam splitter and a polarization controller to control polarization of one light from the optical splitter so that the polarization direction of the second signal light included in one portion of the lights from the optical splitter coincides with that of the first polarization beam splitter and to apply the polarization-controlled light to the first polarization beam splitter. Furthermore, the second signal light extractor comprises a second polarization beam splitter and a polarization controller to control polarization of the other light from the optical splitter so that a polarization direction of the first signal light included in the other light from the optical splitter coincides with that of the second polarization beam splitter and to apply the controlled light to the second polarization beam splitter.

[0011] In the optical transmission system according to the present invention, preferably the optical transmitter further comprises a laser light source, wherein the first signal light output unit comprises a first VSB mod-

ulator to VSB-modulates an output light from the laser light source with the first data and the second signal light output unit comprises a second VSB modulator to VSB-modulates an output light from the laser light source with the second data.

[0012] In the optical transmission system according to the present invention, preferably the optical transmitter further comprises first and second laser light sources having a wavelength different from each other, wherein the first signal light output unit comprises a first VSB modulator to VSB-modulate an output light from the first laser light source with the first data and the second signal light output unit comprises a second VSB modulator to VSB-modulate an output light from the second laser light source with the second data.

[0013] In the optical transmission system according to the present invention, preferably the optical coupler comprises a polarization coupler to couple the first signal light and the second signal light under polarizations orthogonal to each other.

[0014] In the optical transmission system according to the present invention, preferably the optical coupler comprises a coupler to couple the first signal light and the second signal light under polarization directions different from each other on timeslots different from each other.

[0015] In the optical transmission system according to the present invention, preferably the optical transmitter comprises a polarization controller to control a polarization direction of the second signal light from the second signal light output unit, and the optical separator comprises a polarization beam splitter and a polarization tracking unit to control polarization of the light from the optical transmission line so that a polarization direction of the first signal light included in the light from the optical transmission line coincides with a first polarization direction of the polarization beam splitter, to apply the polarization-controlled light to the polarization beam splitter, and to control the polarization controller so that a polarization direction of the second signal light included in the light from the optical transmission line coincides with a second polarization direction orthogonal to the first polarization direction of the polarization beam splitter.

[0016] In the optical transmission system according to the present invention, preferably the optical transmitter comprises a first polarization controller to control polarization of the second signal light from the second signal light output unit. The optical separator comprises a second polarization controller to control polarization of the light from the optical transmission line, a polarization beam splitter to split a light from the second polarization controller into first and second optical components having a polarization direction orthogonal to each other, a first power detector to detect power of the first optical component and control the second polarization controller so as to increase the detected result, and a second power detector to detect power of the second optical component and control the first polarization controller so as to increase the detected result.

[0017] In an optical transmission method according to the present invention, a first signal light is generated by modulating a first optical carrier using VSB modulation having a sideband on a short wavelength side according to a first data. A second signal light is generated by modulating a second optical carrier using VSB modulation having a sideband on a long wavelength side according to a second data. The first signal light and the second signal light are multiplexed under polarizations different form each other and output onto an optical transmission line. First optical component mainly including the first signal light and second optical component mainly including the second signal light are separated out of the light from the optical transmission line. The first data is restored from the first optical component and the second data is restored from the second optical component.

[0018] Preferably, in the optical transmission method according to the present invention, the output light from the laser light source is divided into two portions to generate the first optical carrier and the second optical carrier.

[0019] Preferably, in the optical transmission method according to the present invention, the first signal light and the second signal light are multiplexed under polarization directions different from each other on timeslots different from each other.

[0020] An optical transmitter according to the present invention comprises a first signal light output unit to output a first signal light of linear polarization to carry a first data using VSB modulation having a sideband on a short wavelength side, a second signal light output unit to output a second signal light of linear polarization to carry a second data using VSB modulation having a sideband on a long wavelength side, and an optical coupler to couple the first signal light and the second signal light under polarization directions different from each other and output the coupled signal lights onto the optical transmission line.

[0021] Preferably, the optical transmitter according to the present invention further comprises a laser light source, wherein the first signal light output unit comprises a first VSB modulator to VSB-modulate an output light from the laser light source with the first data and the second signal light output unit comprises a second VSB modulator to VSB-modulate an output light from the laser light source with the second data.

[0022] Preferably, the optical transmitter according to the present invention further comprises first and second laser light sources having a wavelength different from each other, wherein the first signal light output unit comprises a first VSB modulator to VSB-modulate an output light from the first laser light source with the first data and the second signal light output unit comprises a second VSB modulator to VSB-modulate an output light from the second laser light source with the second data.

[0023] Preferably, in the optical transmitter according

to the present invention, the optical coupler comprises a polarization coupler to couple the first signal light and the second signal light under polarizations orthogonal to each other.

[0024] Preferably, in the optical transmitter according to the present invention, the optical coupler comprises a coupler to couple the first signal light and the second signal light under polarization directions different from each other on timeslots different from each other.

[0025] Preferably, the optical transmitter according to the present invention further comprises a polarization controller to control polarization of the second signal light from the second signal light output unit and apply the polarization-controlled signal to the optical coupler, wherein the polarization controller is controlled by a control signal from an optical receiver for receiving the second signal light.

[0026] An optical transmission method according to the present invention comprises steps of generating a first signal light by modulating a first optical carrier using VSB modulation having a sideband on a short wavelength side according to a first data, generating a second signal light by modulating a second optical carrier using VSB modulation having a sideband on a long wavelength side according to a second data, and multiplexing the first signal light and the second signal light under polarization directions different from each other to output onto an optical transmission line.

[0027] Preferably, in the optical transmission method according to the present invention, an output light from a laser light source is divided into two portions to generate the first optical carrier and the second optical carrier.

[0028] Preferably, in the optical transmission method according to the present invention, the first signal light and the second signal light are multiplexed under polarization directions different from each other on timeslots different from each other and output onto an optical transmission line.

BRIEF DESCRIPTION OF THE DRAWING

[0029] The above and other objects, features and advantages of the present invention will be apparent from the following detailed description of the preferred embodiments of the invention in conjunction with the accompanying drawings, in which:

Fig. 1 shows a schematic block diagram of a first embodiment of the invention;
Fig. 2 is a schematic diagram of a spectrum of an output light from a polarization beam splitter 26;
Fig. 3 is a schematic block diagram of a polarization tracking unit 30;
Fig. 4 is a schematic diagram of a spectrum of a received signal;
Fig. 5(A) shows a relation between a spectral distribution of a signal light Sa and ideal transmission characteristics of an optical filter 34A;
Fig. 5(B) shows a relation between a spectral distribution of a signal light Sb and ideal transmission characteristics of an optical filter 34B;
Fig. 6 shows an actual filter characteristic diagram of the optical filter 34A;
Fig. 7 shows a schematic diagram of a spectrum in which a wavelength of optical carrier is shifted by approximately 12.5 GHz (=0.1 nm);
Fig. 8 shows a schematic block diagram of an optical receiver 14a in a second embodiment of the present invention;
Fig. 9 shows a schematic block diagram of a third embodiment of the present invention;
Fig. 10 shows a schematic block diagram of an optical receiver 114a in which an optical receiver 114 is partly modified;
Fig. 11 shows a schematic block diagram of an optical transmitter modified for combining the time-division-multiplex;
Fig. 12 shows a schematic block diagram of another configuration of an optical transmitter modified for combining the time-division-multiplex;
Fig. 13 shows a timing example of signal lights S1 and S2 having been polarization-multiplexed and time-division-multiplexed; and
Fig. 14 shows waveform examples of two signals in an optical receiver after getting polarization-demultiplexed.

DETAILED DESCRIPTION

[0030] Embodiments of the invention are explained below in detail with reference to the drawings.

(A first embodiment)

[0031] Fig. 1 shows a schematic block diagram of a first embodiment of the present invention. A signal light from an optical transmitter 10 propagates on an optical transmission line 12 and enters an optical receiver 14. The optical transmission line 12 comprises, for example, a repeaterless optical fiber transmission line having only optical fibers or an optical amplifier repeater transmission line in which a plurality of optical fibers are connected in serial with optical repeater amplifiers.

[0032] A laser light source 20 outputs a CW laser light having a signal wavelength λs. A splitter 22 splits the output light from the laser light source 20 into two portions and applies one portion to a VSB modulator 24A and the other to a VSB modulator 24B. The VSB modulator 24AVSB-modulates the input laser light with a data D1 and applies the signal light S1 of linear polarization to a polarization beam splitter 26. The VSB modulator 24B VSB-modulates the input laser light with a data D2 and applies the signal light S2 of linear polarization to the polarization beam splitter 26. Here, while the VSB modulator 24A eliminates a sideband on a long wave-

length side (or on a short wavelength side), the VSB modulator 24B eliminates a sideband on a short wavelength side (or on a long wavelength side).

[0033] VSB modulation eliminates most (SSB modulation eliminates all) of one sideband generated by intensity modulation and can be realized by adding a phase modulator or an optical filter to an existing data modulator in order to eliminate unnecessary band components. Since the present invention does not intend to propose a new configuration of a VSB modulator, further explanation about the VSB modulators 24A and 24B is omitted.

[0034] The polarization beam splitter 26 couples the signal lights S1 and S2 from the VSB modulators 24A and 24B with polarization directions orthogonal to each other and outputs onto an optical transmission line 12. Fig. 2 shows a schematic spectral diagram of an output light from the polarization beam splitter 26. To make it easily understandable, the signal lights S1 and S2 from the VSB modulators 24A and 24B are shown in orthogonal polarization state.

[0035] The signal lights propagated on the optical transmission line 12 enter an optical receiver 14. In the optical receiver 14, a polarization tracking unit 30 monitors optical power of an input signal light having one polarization (e.g. the signal light S1 from the optical transmission line 12 and automatically controls a polarization direction of the signal light so as to coincide with one polarization direction of the polarization beam splitter 32 according to the monitored result.

[0036] Fig. 3 shows a schematic diagram of the polarization tracking unit 30. The input light of the polarization tracking unit 30 from the optical transmission line 12 first enters a polarization controller 40. The polarization controller 40 is capable of controlling polarization of an input light to become linear polarization with a desirable direction. Such apparatus is described as a polarization converter in, for example, Japanese Patent Publication Laid-Open No. 2000-356760 corresponding to U.S. Patent Application No. 09/594,856, the entire contents of which are incorporated herein by reference. An optical separator 42 separates a portion out of an output light from the polarization controller 40 and applies it to a polarization beam splitter 44. The polarization beam splitter 44 splits a predetermined polarization direction component out of the light from the optical separator 42 and applies it to a power detector 46. The power detector 46 measures power of the light from the polarization beam splitter 44 and controls the polarization controller 40 so that the measured result becomes maximal.

[0037] Owing to the above feedback control of polarization, the polarization controller 40 controls polarization of an input light into a predetermined polarization direction to be split by the polarization beam splitter 44 regardless of a polarization direction of the input light and then outputs it. However, when the polarization control range of the polarization controller 40 is set too wide, it controls polarization of an input light so as to coincide with an intermediate polarization direction between the two polarization-division-multiplexed orthogonal polarizations. Therefore, it is necessary to narrow the polarization control range of the polarization controller 40 so as to control one of the two polarization-division-multiplexed orthogonal polarizations to become a predetermined polarization direction.

[0038] A polarization beam splitter 32 splits an output light from the polarization tracking unit 30 into a signal light Sa having a polarization component identical to a target polarization direction of the polarization tracking unit 30 and a signal light Sb having polarization orthogonal to the polarization direction component of the signal light Sa. The orthogonality of polarizations between the signal lights S1 and S2 becomes imperfect due to PMD and PDL of the optical transmission line 12, and thus each of signal lights Sa and Sb split by the polarization beam splitter 32 includes crosstalk.

[0039] As shown in Fig. 4, for example, assuming that the polarization of the signal light S2 is rotated from the original direction by an angle θ, the signal light Sa is expressed as the sum of S1 and S2 sin θ and the signal light Sb as S2 cos θ when the polarization of the signal light S1 is identical to that of the signal light Sa split by the polarization beam splitter 32. S2 sin θ becomes crosstalk against the signal S1 and the signal light S2 is attenuated by cos θ. Assuming that a data D1 is restored from the signal light Sa and a data D2 is restored from the signal light Sb, generally a portion of the signal light S2 is mixed in the signal light Sa as crosstalk, and a portion of the signal light S1 is mixed in the signal light Sb as crosstalk.

[0040] Although it is impossible to eliminate such crosstalk from different polarization in prior art, the present embodiment can efficiently eliminate crosstalk from different polarization using the optical filters 34A and 34B. That is, the optical filter 34A eliminates a sideband component unnecessary for the receiving process of the signal light S1 out of the signal light Sa split by the polarization beam splitter 32 and the optical filter 34B eliminates a sideband component unnecessary for the receiving process of the signal light S2 out of the signal light Sb split by the polarization beam splitter 32. Fig. 5(A) shows a relation between a spectral distribution of the signal light Sa and ideal transmission characteristics of the optical filter 34A and Fig. 5(B) shows a relation between a spectral distribution of the signal light Sb and ideal transmission characteristics of the optical filter 34B.

[0041] Practically, it is difficult to obtain such optical filters 34A and 34B having the steep cut-off characteristics as shown in Figs. 5(A) and 5(B) and actual transmission characteristics of the optical filter 34A, for example, show the gentle cut-off characteristics as shown in Fig. 6. In this case, a portion (the part of the oblique lines) of S2 sinθ becomes crosstalk. To reduce the crosstalk, optical carrier wavelengths of two signal lights to be polarization-division-multiplexed should be sepa-

rated by approximately 12.5 GHz (=0.1 nm). To separate the optical carrier wavelengths, the VSB modulators 24A and 24B respectively should have a laser light source having a wavelength slightly different from the other.

[0042] The receiver 36A and 36B respectively receives a signal light from the optical filter 34A and 34B, restores the data D1 and D2 and outputs it.

(A second embodiment)

[0043] In the embodiment shown in Fig. 1, a polarization tracking unit 30 controls polarization of a received light according to the signal light S1 having one polarization and thus crosstalk is mixed due to the disorder of orthogonality of polarization. Fig. 8 shows a schematic block diagram of an optical receiver 14a to receive both signal lights S1 and S2 with smaller crosstalk.

[0044] A 3dB optical coupler 50 divides an input light from the optical transmission line 12 into two portions and applies one portion to a polarization controller 52A and the other to a polarization controller 52B. The polarization controller 52A and 52B has configuration and function identical to those of the polarization controller 40. Output lights from the polarization controller 52A and 52B enter polarization beam splitters 54A and 54B respectively.

[0045] The polarization beam splitter 54A applies a polarization component of a signal light desired to receive (here, it is assumed to be the signal light S1) to an optical filter 58A and also applies a polarization component orthogonal to the above polarization component to a power detector 56A. Similarly, the polarization beam splitter 54B applies a polarization component desired to receive (here, it is assumed to be the signal light S2) to an optical filter 58B and a polarization component orthogonal to the above polarization component to a power detector 56B. The power detectors 56A and 56B detect optical power having the polarization component applied from the polarization beam splitters 54A and 54B and control the polarization controllers 52A and 52B so that the optical power becomes maximal respectively.

[0046] Owing to the above control, polarization of output light from the polarization controller 52A is controlled to coincide with a polarization direction of the signal light S2 and polarization of output light from polarization controller 52B is controlled to coincide with a polarization direction of the signal light S1 Accordingly, the signal light entered the optical filter 58A ideally comprises only the signal light S1, and the signal light entered the optical filter 58B comprises only the signal light S2 . In other words, the signal light entered the optical filter 58A does not include the crosstalk of the signal light S2, and the signal light entered the optical filter 58B does not include the crosstalk of the signal light S1

[0047] In a configuration shown in Fig. 8, since each of the signal lights entered the optical filter 58A and 58B does not include the signal light component of the other polarization, the cut-off characteristics of the optical filters 58A and 58B do not need to be steep. Also, it is even possible to omit the optical filters 58A and 58B.

(A third embodiment)

[0048] Fig. 9 shows a schematic block diagram of a third embodiment according to the present invention. In this embodiment, a polarization tracking unit disposed on each of transmitter and receiver reduces crosstalk between orthogonal polarization components.

[0049] A signal light from a transmitter 110 propagates on an optical transmission line 112 and enters an optical receiver 114. The optical transmission line 112, similarly to the optical transmission 12, comprises a repeaterless optical fiber transmission line composed of optical fibers alone or an optical amplifier repeater transmission line in which a plurality of optical fibers are connected in serial by optical repeater amplifiers.

[0050] A laser light source 120 outputs a CW laser light of signal wavelength λs. A splitter 122 splits the output light from the laser light source 120 into two portions and applies one portion to a VSB modulation 124A and the other to a VSB modulator 124B. The VSB modulator 124A VSB-modulates the input laser light with a data D1 and outputs a signal light S1 having linear polarization to a 3dB optical coupler 126. The VSB modulator 124B VSB-modulates the input laser light with a data D2 and outputs a signal light S2 having linear polarization to a polarization controller 128. The polarization controller 128 controls the polarization of the signal light S2 from the VSB modulator 124B to become a designated direction according to a control signal from an optical receiver 114. An output light from the polarization controller 128 enters a 3 dB optical coupler 126. Similarly to the embodiment shown in Fig. 1, when the VSB modulator 124A eliminates a sideband on a long wavelength side (or on a short wavelength side), the VSB modulator 124B eliminates a sideband on a short wavelength side (or on a long wavelength side).

[0051] The 3 dB optical coupler 126 couples the signal light S1 from the VSB modulator 124A and the signal light S2 from the polarization controller 128 and outputs onto the optical transmission line 112.

[0052] The signal lights propagated on the optical transmission line 112 enter the optical receiver 114. In the optical receiver 114, a polarization tracking unit 130, similarly to the polarization tracking unit 30, monitors optical power of a signal light having one polarization (e.g. the signal light S1) from the optical transmission line 112 and automatically controls the polarization direction of the signal light so as to coincide with one polarization direction of a polarization beam splitter 132 according to the monitored result. The polarization tracking unit 130 also monitors optical power of a signal light having the other polarization (e.g. the signal light S2) and controls a polarization direction of the signal light S2 using

the polarization controller 128 so that the polarization direction of the signal light S2 becomes orthogonal to that of the signal light S1 at the polarization tracking unit 130 according to the monitored result.

[0053] The polarization beam splitter 132 splits an output light from the polarization tracking unit 130 into two orthogonal polarization components Sa and Sb and applies the component Sa to the optical filter 134A and the component Sb to the optical filter 134B. Owing to the polarization tracking units 128 and 130, the component Sa ideally comprises only the signal light S1 (or S2), and the component Sb comprises only the signal light S2 (or S1) That is, the crosstalk becomes so small that it can be negligible. Even though the polarization directions of the signal lights S1 and S2 vary while propagating on the optical transmission line 112 due to PMD and PDL of the optical transmission line 112, the polarization directions of the signal lights S1 and S2 are in the condition to be orthogonal when they enter the polarization beam splitter 132. Therefore, it is not necessary to have such steep cut-off characteristics shown in Figs. 5(A) and 5(B) for the transmission factor of the optical filters 134 A and 134B.

[0054] The optical filter 134A eliminates a sideband component unnecessary for the receiving process of the signal light S1 out of the signal light Sa split by the polarization beam splitter 132, and the optical filter 134B eliminates a sideband component unnecessary for the receiving process of the signal light S2 out of the signal light Sb split by the polarization beam splitter 132. Receivers 136A and 136B receive a signal light from the optical filters 134A and 134B, and restore and output the data D1 and D2 respectively.

(A fourth embodiment)

[0055] Fig. 10 shows a schematic block diagram of an optical receiving apparatus 114a in which a part of the optical receiving apparatus 114 is modified. In an embodiment shown in Fig. 10, the polarization tracking unit 130 and the polarization beam splitter 132 are unified.

[0056] That is, a light entered the optical receiver 114a from the optical transmission line 112 firstly inputs a polarization controller 140. The polarization controller 140 has configuration and function identical to those of the polarization controller 40 and controls polarization of the input light to become linear polarization having any polarization direction specified by an outer control signal.

[0057] The polarization beam splitter 142 splits an output light from the polarization controller 140 into two linear polarization components Sa and Sb orthogonal to each other and applies the component Sa to an optical filter 144A and the component Sb to an optical filter 144B. Here, it is assumed that the signal light Sa comprises mainly the signal light S1 and the signal light Sb comprises mainly the signal light S2. The optical filter 144A eliminates a sideband component unnecessary to the receiving process of the signal light S1 out of the signal light Sa split by the polarization beam splitter 142, and the optical filter 144B eliminates a sideband component unnecessary for the receiving process of the signal light S2 out of the signal light Sb split by the polarization beam splitter 142.

[0058] An optical splitter 146A applies most of the output light from the optical filter 144A to a receiver 148A and the rest to a power detector 150A. Similarly, an optical splitter 146B applies most of the output light from the optical filter 144B to a receiver 148B and the rest to a power detector 150B.

[0059] The receivers 148A and 148B receive the signal lights Sa and Sb from the optical splitters 146A and 146B, restore the data D1 and D2, and output them respectively.

[0060] The power detector 150A detects the power of light from the optical splitter 146A and controls the polarization controller 140 so that the detecting power becomes maximal. Accordingly, the polarization controller 140 controls a polarization direction of a light entered from the optical transmission line 112 so that the signal light S1 in the output light from the polarization controller 140 is maximally split as the signal light Sa. With this operation, the receiving of the signal light S1 is optimized and ideally the signal light S1 does not mix in the signal light Sb as crosstalk.

[0061] On the other hand, the power detector 150B detects the power of light from the optical splitter 146B and controls the polarization controller 128 so that the detected power becomes maximal. Accordingly, the polarization controller 128 controls a polarization direction of the output signal light S2 from the VSB modulator 124B so that the signal light S2 in the output light from the polarization controller 140 is maximally split as the signal light Sb. Consequently, the polarization direction of the signal light S2 becomes completely orthogonal to the polarization direction of the signal light S1 at the output of the polarization controller 140. Owing to the control, the receiving of the signal light S2 is optimized and ideally the signal light S2 does not mix in the signal light Sa as crosstalk.

[0062] As stated above, in the configuration shown in Fig. 10, the polarization directions of the signal lights S1 and S2 become completely orthogonal in theory, and the polarization beam splitter 142 can split the signal lights S1 and S2 completely, namely without any crosstalk.

(A fifth embodiment)

[0063] It became clear that, when two VSB modulated signal lights, which suppressed sidebands are different from each other, are merely coupled at the same timing, it is necessary to suppress the crosstalk with a sufficiently high suppression factor (40 dB or more). This is because optical carriers of both VSB modulated lights interfere with each other to generate so-called coherent crosstalk.

[0064] It is possible to prevent the coherent crosstalk

between the optical carriers of the two VSB modulated lights by time-division-multiplexing the two VSB modulated lights. Fig. 11 shows a schematic block diagram wherein the optical transmitter 10 in Fig. 1 is modified to have such function as an optical transmitter 210a, and Fig. 12 shows a schematic block diagram wherein the optical transmitter 110 in Fig. 9 is modified as an optical transmitter 210b. Fig. 13 shows a time waveform example after VSB modulated signals S1 and S2 are time-division-multiplexed.

[0065] In the optical transmitter 210a shown in Fig. 12, an optical delay unit 212a of delay time τ is disposed between a VSB modulator 24A and PBS 26. In an optical transmitter 210b shown in Fig. 13, an optical delay unit 212b of delay time τ is disposed between a VSB modulator 124A and a 3 dB optical coupler 126.

[0066] In Figs. 11 and 12, it is required for both VSB modulated signals S1 and S2 to comprise RZ optical pulses having a duty factor of 50% or less. Assuming that the pulse period is T, the delay time τ of the optical delay units 212a and 212b is set to T/2. With this configuration, as shown in Fig. 13, the VSB modulated signal light S1 and the VSB modulated signal light S2 are time-division-multiplexed. Fig. 14 shows a waveform example when the signal lights S1 and S2, which were polarization-multiplexed and time-division-multiplexed as shown in Fig. 13, are polarization-demultiplexed. After the polarization-demultiplex, in an optical component Sa comprising mainly the signal light S1 the crosstalk from the signal light S2 is mixed between optical pulses carrying the data D1. Similarly, after the polarization-demultiplex, in an optical component Sb comprising mainly the signal light S2, the crosstalk from the signal light S1 is mixed between optical pulses carrying the data D2. Such crosstalk can be simply suppressed by disposing an optical gate to transmit the optical pulse part carrying the data D1, D2 and to suppress the other parts. However, since the two VSB signal lights S1 and S2 are arranged on different timeslots in the time domain, such serious signal deterioration caused by the coherent crosstalk does not occur even if an optical gate is not disposed.

[0067] Obviously, although the signal light S1 is delayed in Figs. 11 and 12, it is also applicable to delay the signal light S2. For instance, it is applicable to dispose an optical delay unit equivalent to the optical delay unit 212a between the VSB modulator 24B and the PBS 26. Also, it is applicable to dispose an optical delay unit equivalent to the optical delay unit 212b between the VSB 124B and the polarization controller 128 or between the polarization controller 128 and the 3 dB optical coupler 126 . Furthermore, it is applicable to dispose optical delay units equivalent to the optical delay units 212a and 212b at the input side of the VSB modulator 24A or 24B.

(The others)

[0068] It is applicable for each embodiment shown in Figs. 8, 9, and 10 to slightly shift optical carrier wavelengths of the two signal lights S1 and S2

[0069] In the above each embodiment, good transmission characteristics are realized using polarization division multiplexing and VSB modulation together. By using the polarization division multiplexing, intervals of wavelengths can widen twice as much in the same transmission capacity. That is, the resolution of a wavelength division multiplexer in wavelength division multiplexing transmission is relieved twice as much. For instance, a wavelength division multiplexer with the resolution of 0.4 nm can be used instead of a wavelength division multiplexer with the resolution of 0.2 nm and this reduces the system costs.

[0070] As readily understandable from the aforementioned explanation, according to the invention, it is possible to realize satisfactory transmission characteristics by combining orthogonal polarization multiplexing and VSB modulation. For example, it is even possible to realize such a long haul transmission as transoceanic transmission.

[0071] By utilizing the polarization multiplex and the time division multiplex at the same time, it is possible to greatly reduce the coherent crosstalk. Owing to the polarization multiplex, the interference hardly occurs at the overlapped part of pulses between the signal lights S1 and S2 . Therefore, in the present invention, it is possible to make the pulse width of the signal pulses of the signal lights S1 and S2 wider compared to that in the case wherein the time-division-multiplex alone is utilized. Accordingly, the load of specs for the laser light source, VSB modulator and optical receiver is reduced.

[0072] While the invention has been described with reference to the specific embodiment, it will be apparent to those skilled in the art that various changes and modifications can be made to the specific embodiment without departing from the spirit and scope of the invention as defined in the claims.

Claims

1. An optical transmission system comprising an optical transmitter (10, 110, 210a, 210b), an optical transmission line (12, 112), and an optical receiver (14, 114) wherein

    the optical transmitter (10, 110, 210a, 210b) comprises

        a first signal light output unit (24A, 124A) to output a first signal light (S1) of linear polarization to carry a first data (D1) using VSB modulation having one of sideband on a short wavelength side and sideband on

a long wavelength side;
a second signal light output unit (24B, 124B) to output a second signal light (S2) of linear polarization to carry a second data (D2) using VSB modulation having the other of sideband on a short wavelength side and sideband on a long wavelength side; and
an optical coupler (26; 126; 26, 212a; 126, 212b) to couple the first signal light (S1)and the second signal light (S2) under different polarizations and output the coupled signal lights onto the optical transmission line (12, 112); and

the optical receiver (14, 114) comprises

an optical separator (30, 32; 130, 132) to separate a first optical component (Sa) mainly including the first signal light (S1) and a second optical component (Sb) mainly including the second signal light (S2) out of the input light from the optical transmission line (12, 112);
a first receiver (36A, 136A) to restore the first data (D1) from the first optical component (Sa); and
a second receiver (36B, 136B) to restore the second data (D2) from the second optical component (Sb).

2. The system of claim 1 wherein

the optical separator comprises

a polarization beam splitter (32); and
a polarization tracking unit (30) to control polarization of the input light from the optical transmission line (12) so that one of polarization directions of the first and second signal lights (S1 S2) included in the input light from the optical transmission line (12) coincides with that of the polarization beam splitter (32).

3. The system of claim 1 wherein

the optical separator comprises

an optical splitter (50) to split the input light from the optical transmission line (12) into two portions;
a first signal light extractor (52A, 54A, 56A) to extract the first signal light (S1) out of one portion output light from the optical splitter (50); and
a second signal light extractor (52B, 54B, 56B) to extract the second signal light (S2) out of the other portion output light from the optical splitter (50).

4. The system of claim 3 wherein

the first signal light extractor comprises

a first polarization beam splitter (54A); and
a polarization controller (52A, 56A) to control a polarization of one portion from the optical splitter (50) so that a polarization direction of the second signal light (S2) included in one portion from the optical splitter (50) coincides with that of the first polarization beam splitter (54A) and to apply the polarization-controlled light to the first polarization beam splitter (54A); and

the second signal light extractor comprises

a second polarization beam splitter (54B); and
a polarization controller (52B, 56B) to control a polarization direction of the other portion from the optical splitter (54B) so that a polarization direction of the first signal light (S1) included in the other portion from the optical splitter (50) coincides with a polarization direction of the second polarization beam splitter (54B) and to apply the polarization-controlled light to the second polarization beam splitter (54B).

5. The system of claim 1 to 4 wherein

the optical transmitter (10, 110, 210a, 210b) further comprises a laser light source (20, 120);
the first signal light output unit comprises a first VSB modulator (24A, 124A) to VSB-modulate an output light from the laser light source with the first data; and
the second signal light output unit comprises a second VSB modulator (24B, 124B) to VSB-modulate the output light from the laser light source with the second data.

6. The system of claim 1 to 4 wherein

the optical transmitter (10, 110) further comprises first and second laser light sources having a wavelength different from each other;
the first signal light output unit comprises a first VSB modulator (24A, 124A) to VSB-modulate an output light from the first laser light source with the first data; and
the second signal light output unit comprises a second VSB modulator (24B, 124B) to VSB-modulate an output light from the second laser

light source with the second data.

7. The system of claim 1 to 6 wherein the optical coupler comprises a polarization coupler (26) to couple the first and second signal lights (S1, S2) under polarizations orthogonal to each other.

8. The system of claim 1 to 6 wherein the optical coupler comprises a coupler (26, 212a; 126, 212b) to couple the first and second signal lights (S1, S2) under polarization directions different from each other on timeslots different from each other.

9. The system of claim 1 wherein

the optical transmitter (110, 210b) comprises a polarization controller (128) to control a polarization direction of the second signal light (S2) from the second signal light output unit (124B); and
the optical separator comprises

a polarization beam splitter (132); and
a polarization tracking unit (130) to control a polarization direction of an input light from the optical transmission line (112) so that a polarization direction of the first signal light (S1) included in the input light from the optical transmission line (112) coincides with a first polarization direction of the polarization beam splitter (132), to apply the polarization-controlled light to the polarization beam splitter (132), and to control the polarization controller (128) so that a polarization direction of the second signal light (S2) included in the input light from the optical transmission line (112) coincides with a second polarization direction orthogonal to the first polarization direction of the polarization beam splitter (132).

10. The system of claim 1 wherein

the optical transmitter (110, 210b) further comprises a first polarization controller (128) to control a polarization direction of the second signal light (S2) from the second signal light output unit (124B); and
the optical separator comprises

a second polarization controller (140) to control a polarization direction of the input light from the optical transmission line (112);
a polarization beam splitter (142) to split an output light from the second polarization controller (140) into the first and second optical components (Sa, Sb) having a polarization direction orthogonal to each other;
a first power detector (150A) to detect power of the first optical component (Sa) and control the second polarization controller (140) so as to increase the detected result; and
a second power detector (150B) to detect power of the second optical component (Sb) and control the first polarization controller (128) so as to increase the detected result.

11. An optical transmission method comprising steps of:

generating a first signal light (S1) by modulating a first optical carrier with VSB-modulation having a sideband on a short wavelength side according to a first data (D1);
generating a second signal light (S2) by modulating a second optical carrier with VSB modulation having a sideband on a long wavelength side according to a second data (D2);
multiplexing the first signal light (S1 and second signal light (S2) under different polarizations to output onto an optical transmission line;
separating a first optical component (Sa) mainly including the first signal light (S1 and a second optical component (Sb) mainly including the second signal light (S2) out of an input light from the optical transmission line;
restoring the first data (D1) from the first optical component (Sa); and
restoring the second data (D2) from the second optical component (Sb).

12. The method of claim 11 further comprises a step of separating an output light from a laser light source into two portions to generate the first optical carrier and the second optical carrier.

13. The method of claim 11 wherein the step of multiplexing the first signal light (S1) and second signal light (S2) under different polarizations to output onto the optical transmission line is a step of multiplexing the first signal light (S1) and the second signal light (S2) under polarization directions different from each other on timeslots different from each other and outputting onto the optical transmission line.

14. An optical transmitter comprising:

a first signal light output unit (24A, 124A) to output a first signal light (S1) of a linear polarization to carry a first data (D1) using VSB modulation having a sideband on a short wavelength side ;
a second signal light output unit (24B, 124B) to

output a second signal light (S2) of a linear polarization to carry a second data (D2) using VSB modulation having a sideband on a long wavelength side; and
an optical coupler (26; 126; 26, 212a; 126, 212b) to couple the first signal light (S1) and the second signal light (S2) under polarization directions different from each other and output the coupled signal lights onto the optical transmission line (12, 112).

15. The optical transmitter of claim 14 further comprising a laser light source (20, 120) wherein

the first signal light output unit comprises a first VSB modulator (24A, 124A) to VSB-modulate an output light from the laser light source with the first data; and
the second signal light output unit comprises a second VSB modulator (24B, 124B) to VSB-modulate the output light from the laser light source with the second data.

16. The optical transmitter of claim 14 further comprising first and second laser light sources having a wavelength different from each other wherein

the first signal light output unit comprises a first VSB modulator (24A, 124A) to VSB-modulate an output light from the first laser light source with the first data; and
the second signal light output unit comprises a second VSB modulator (24B, 124B) to VSB-modulate an output light from the second laser light source with the second data.

17. The optical transmitter of claim 14 wherein the optical coupler comprises a polarization coupler (26) to couple the first signal light and the second signal light under polarizations orthogonal to each other.

18. The optical transmitter of claim 14 wherein the optical coupler comprises a coupler (26, 212a; 126, 212b) to couple the first signal light (S1) and the second signal light (S2) under polarization directions different from each other on timeslots different from each other.

19. The optical transmitter of claim 14 further comprising a polarization controller (128) to control a polarization direction of the second signal light (S2) from the second signal light output unit (124B) and apply to the optical coupler (126) wherein the polarization controller (128) is controlled by a control signal from an optical receiver to receive the second signal light.

20. An optical transmission method comprising steps of:

generating a first signal light (S1) by modulating a first optical carrier using VSB modulation having a sideband on a short wavelength side according to a first data (D1);
generating a second signal light by (S2) modulating a second optical carrier using VSB modulation having a sideband on a long wavelength side according to a second data (D2); and
multiplexing the first signal light (S1) and the second signal light (S2) under polarization directions different from each other to output onto an optical transmission line.

21. The method of claim 20 further separating an output light from a laser light source into two portions to generate the first optical carrier and the second optical carrier.

22. The method of claim 20 wherein the step of multiplexing the first signal light (S1) and the second signal light (S2) under polarization directions different from each other to output onto the optical transmission line is a step of multiplexing the first signal light (S1) and the second signal light (S2) under polarization directions different from each other on timeslots different from each other to output onto the optical transmission line.

Fig. 1

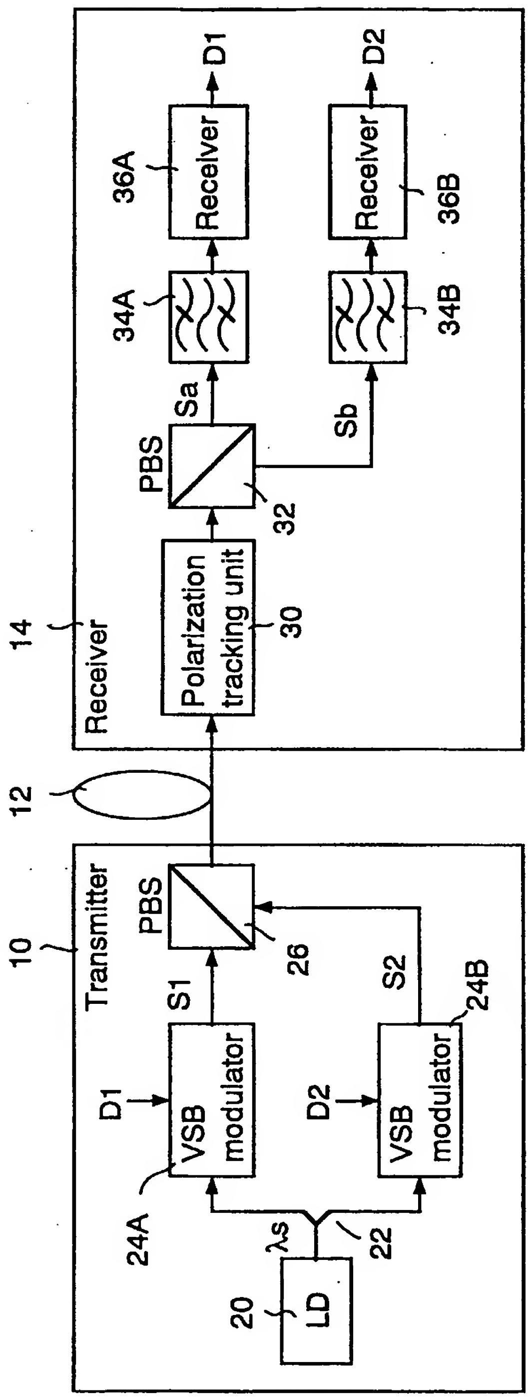

10
Transmitter
20
LD
λs
22
24A
VSB modulator
D1
24B
VSB modulator
D2
S1
S2
PBS
26
12
14
Receiver
Polarization tracking unit
30
PBS
32
Sa
Sb
34A
34B
36A
Receiver
36B
Receiver
D1
D2

Fig. 2

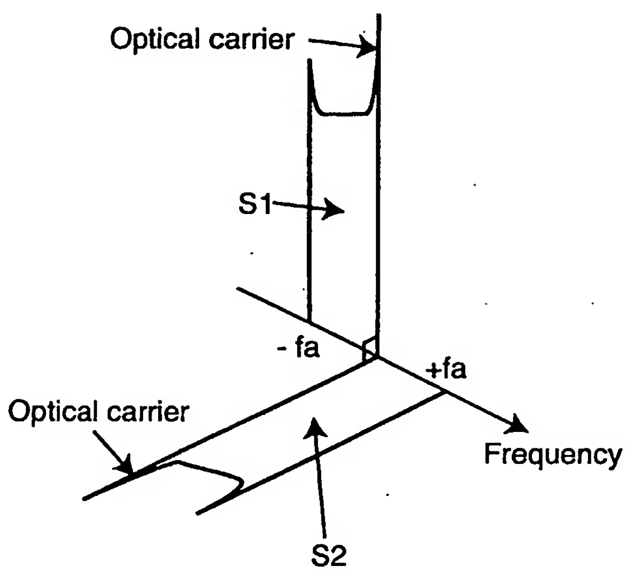


Fig. 3

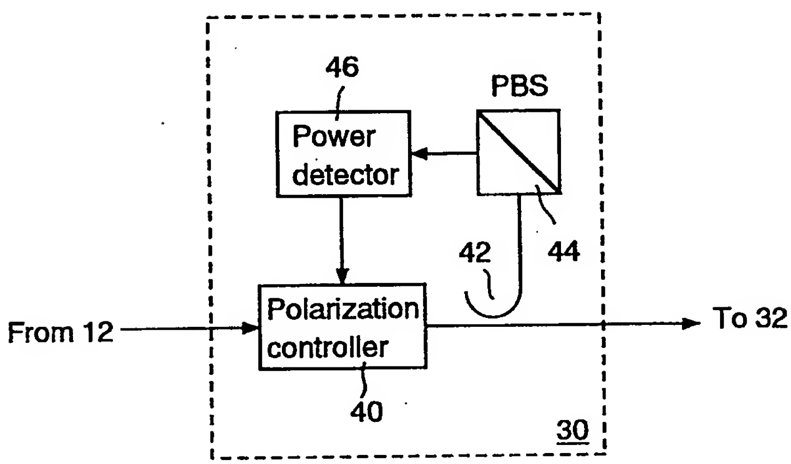

46
PBS
Power detector
42
44
Polarization controller
From 12
To 32
40
30

Fig. 4

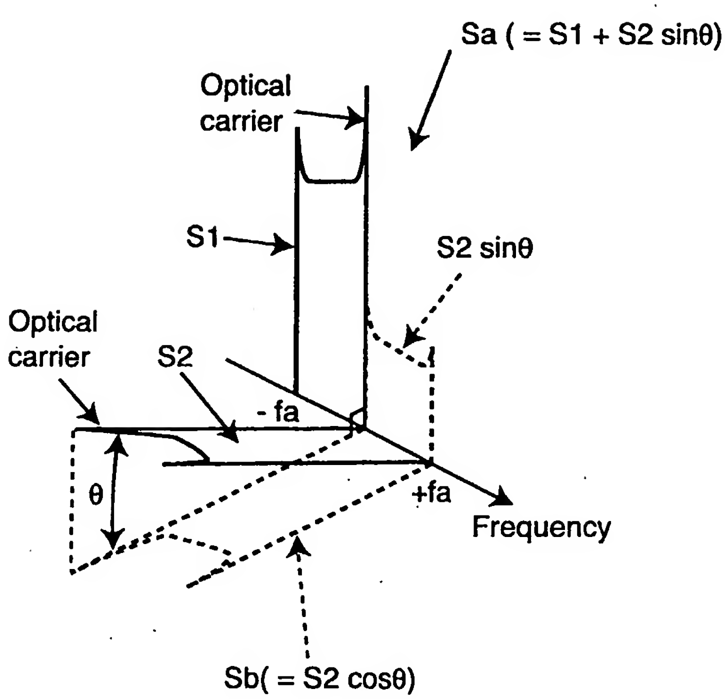

Sa (= S1 + S2 sinθ)
Optical
carrier
S1
S2 sinθ
Optical
carrier
S2
- fa
θ
+fa
Frequency
Sb(= S2 cosθ)

Fig. 5 (A)

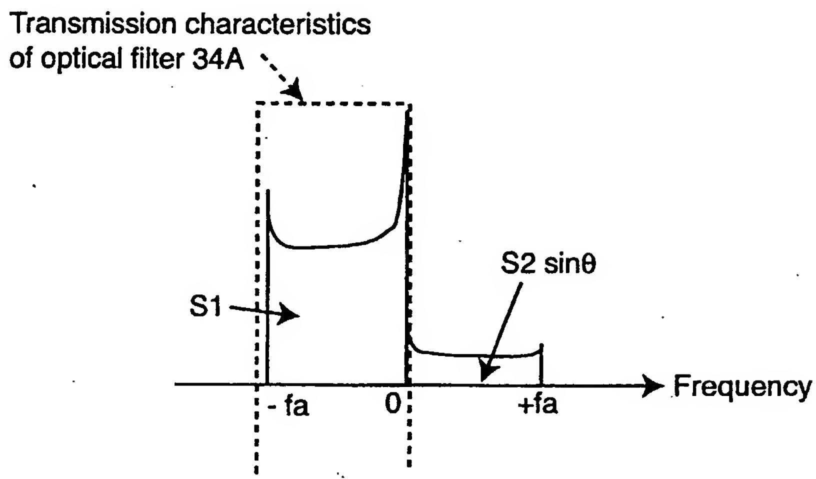

Transmission characteristics
of optical filter 34A
S1
S2 sinθ
- fa
0
+fa
Frequency

Fig. 5(B)

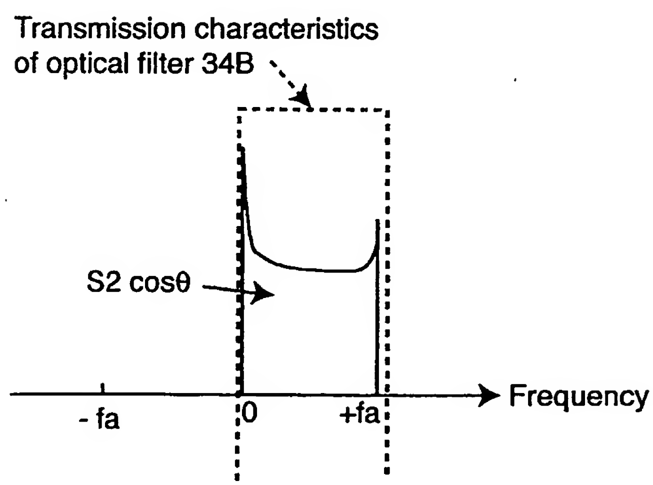

Transmission characteristics
of optical filter 34B
S2 cosθ
- fa
0
+fa
Frequency

Fig. 6

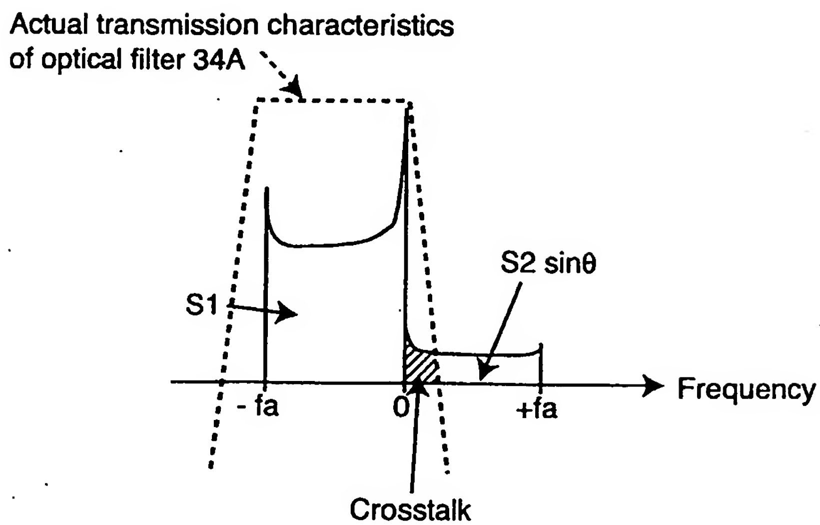

Actual transmission characteristics
of optical filter 34A
S2 sinθ
S1
- fa
0
+fa
Frequency
Crosstalk

Fig. 7

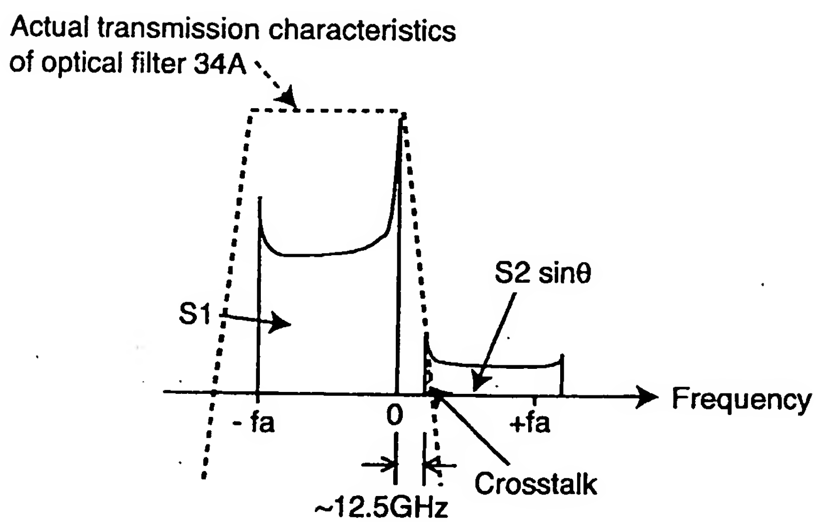

Actual transmission characteristics
of optical filter 34A
S2 sinθ
S1
- fa
0
+fa
Frequency
Crosstalk
~12.5GHz

Fig. 8

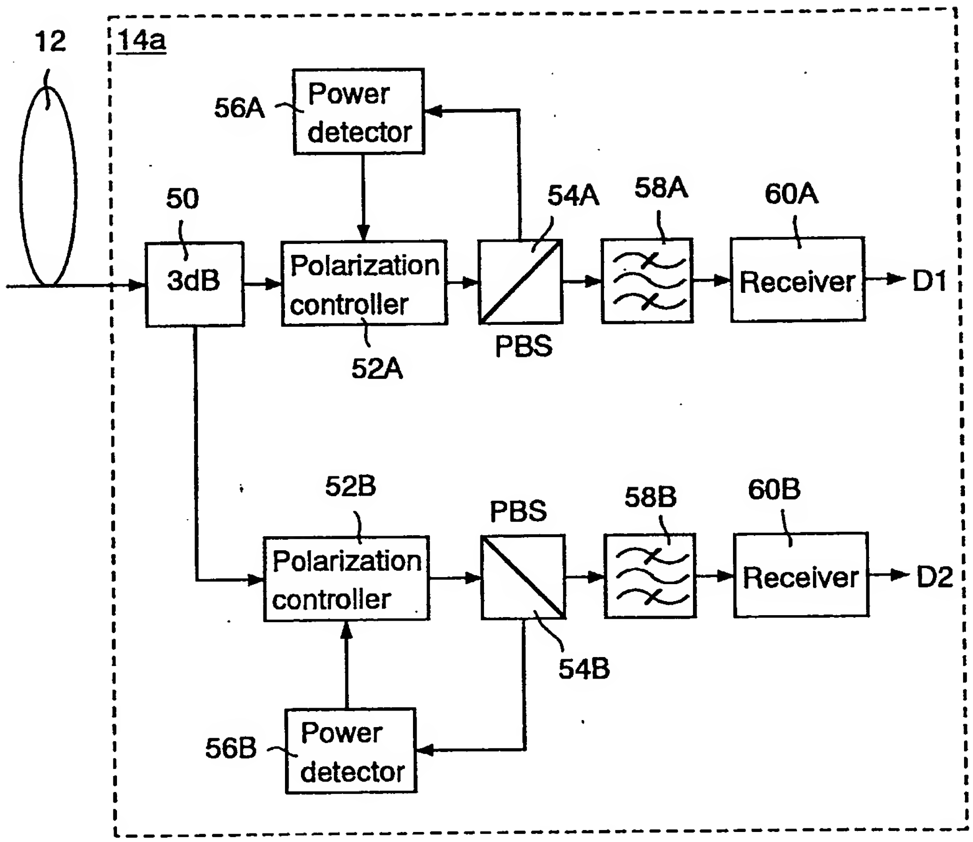
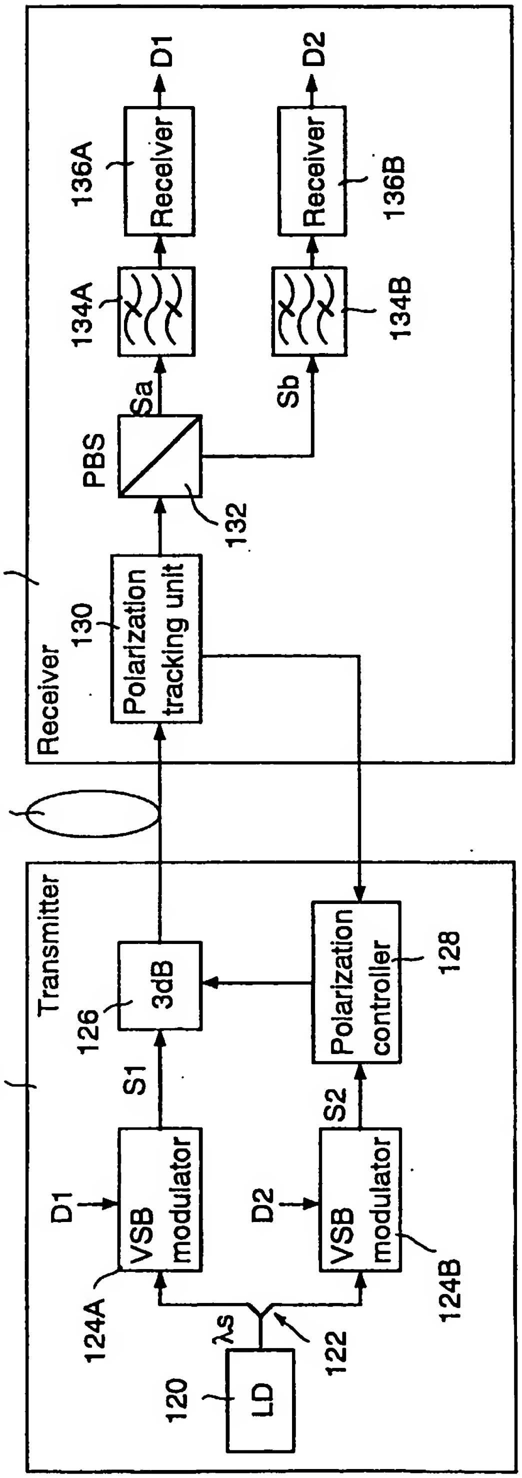

12
14a
56A
Power detector
50
54A
58A
60A
3dB
Polarization controller
Receiver
D1
PBS
52A
52B
PBS
58B
60B
Polarization controller
Receiver
D2
54B
56B
Power detector

Fig. 9



Transmitter
110
LD
120
λs
122
D1
VSB modulator
124A
D2
VSB modulator
124B
S1
S2
3dB
126
Polarization controller
128
112
Receiver
114
Polarization tracking unit
130
PBS
132
Sa
Sb
134A
134B
Receiver
136A
Receiver
136B
D1
D2

Fig. 10

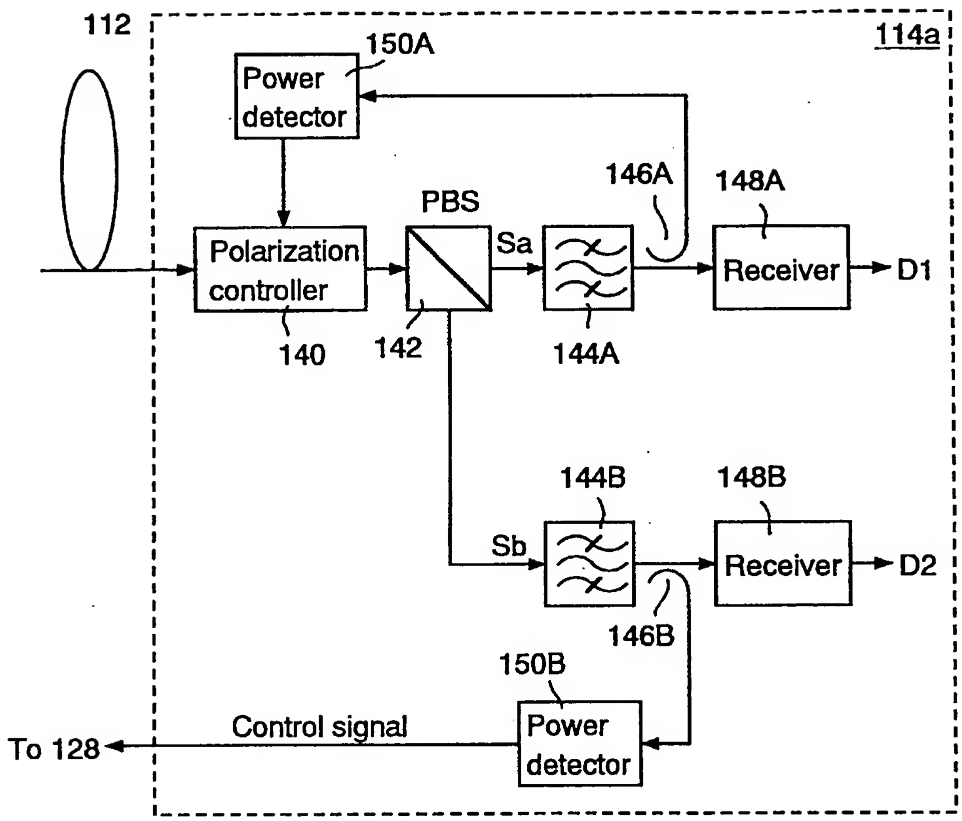

112
114a
150A
Power detector
146A
148A
PBS
Sa
Polarization controller
Receiver
D1
140
142
144A
144B
148B
Sb
Receiver
D2
146B
150B
Control signal
To 128
Power detector

Fig. 11

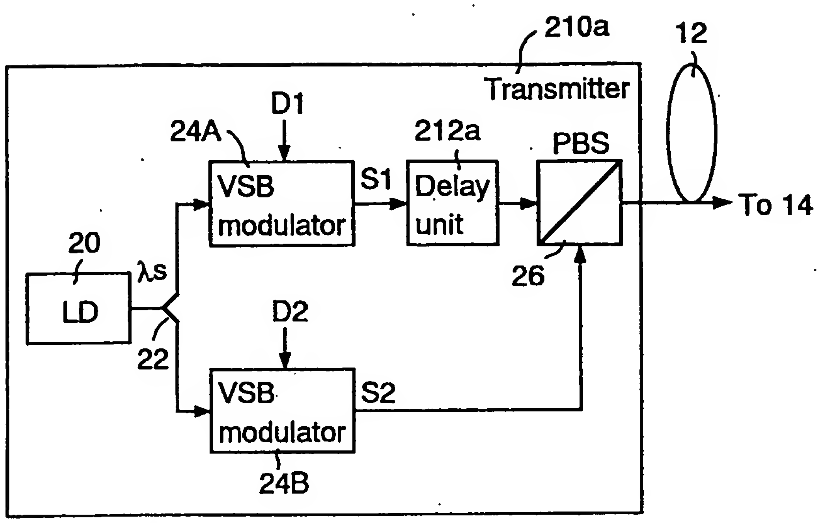

210a
12
Transmitter
D1
24A
212a
PBS
VSB
modulator
S1
Delay
unit
To 14
20
λs
26
LD
22
D2
VSB
modulator
S2
24B

Fig. 12

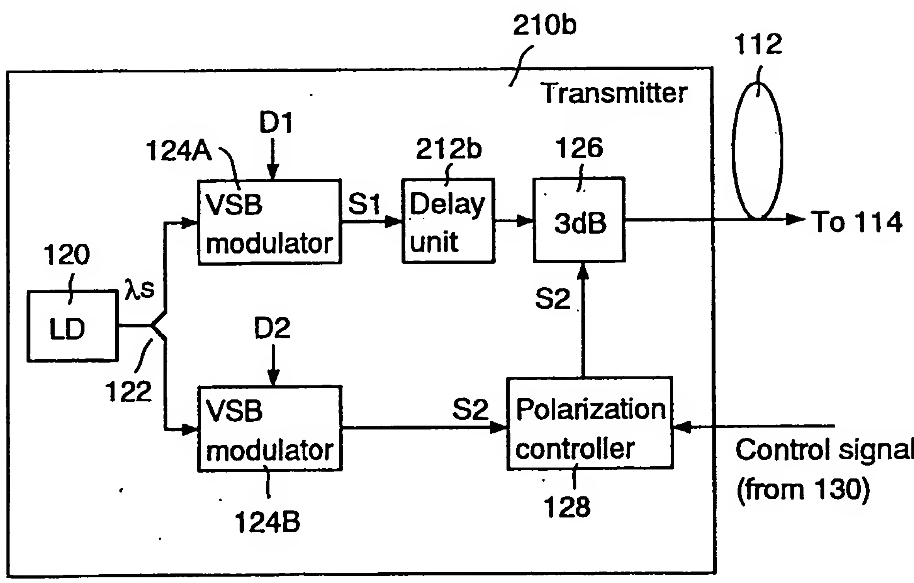

210b
112
Transmitter
D1
124A
212b
126
VSB
modulator
S1
Delay
unit
3dB
To 114
120
λs
S2
LD
D2
122
VSB
modulator
S2
Polarization
controller
Control signal
(from 130)
124B
128

Fig. 13

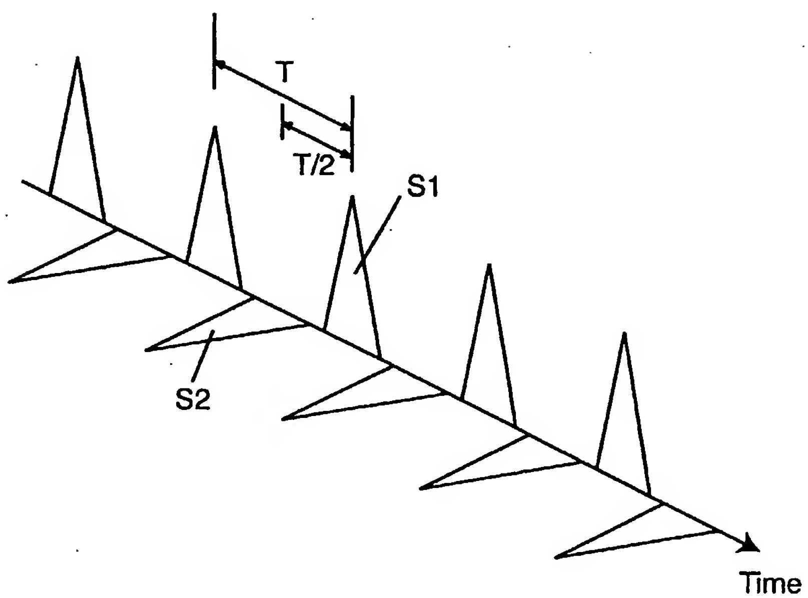


Fig. 14